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SEASAT ECONOMIC ASSESSMENT

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SEASAT ECONOMIC ASSESSMENT

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Principal contributors to the case studies were Mr. C.W. Hamilton of Battelle, Dr. Edward Sherry of JPL, and Captain Paul Wolff of Ocean Data Systems. Mr. Kenneth Hicks and Dr. William Steele of ECON performed the econometric modelling and the operations research required for the generalization of the case study results. Access to the SEASAT users community was provided through the cooperation of the SEASAT Users Working Group chaired by Dr. John Apel of the National Oceanographic and Atmospheric Administration. The NASA Program Manager, Mr. S.W. McCandless helped to focus the diverse organizations and activities that participated in this assessment into the effective team that obtained the results described in the report.

Project Director
SEASAT Economic Assessment
18 September 1974

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1.0 SEASAT PRELIMINARY ECONOMIC ASSESSMENT SUMMARY

The objective of the SEASAT program is to provide scientific and economic benefits from global remote sensing of the ocean's dynamic and physical characteristics. The SEASAT program as presently envisioned consists of:

- SEASAT A - a proof-of-concept satellite planned for launching in 1978
- SEASAT B - to demonstrate a prototype operational system
- OPERATIONAL SEASAT - a fully operational system beginning no later than 1985.

The purpose of the SEASAT economic assessment is to identify, rationalize, quantify and validate the economic benefits evolving from SEASAT. These benefits will arise from improvements in the operating efficiency of systems that interface with the ocean, an efficiency presently constrained by unpredictable or unavoidable variations in ocean state, conditions or weather. Design effectiveness within the systems is also constrained by an imprecise understanding of the dynamic conditions of the design context, which if alleviated, can produce benefits.

SEASAT data will be combined with data from other ocean and atmospheric sampling systems. The data will then be processed through analytical models of the interaction between oceans and atmosphere to yield accurate global measurements and global long range forecasts of ocean conditions and weather, information not currently available. The information made available will be disseminated in a relevant and timely manner to the system's operators so that it can be assimilated into their systems. Assimilation of these measurements and long range forecasts into system's design, planning and operations will result in economic benefits by improving the design and operating efficiencies of these systems that interface with the ocean.

The methodology of this preliminary economic assessment required case study selection, case study benefit development, and the subsequent generalization of the case study benefits. The case studies were selected after a survey of potential applications of the new SEASAT data. The survey was performed by the SEASAT Economic Working Group which both reviewed the pertinent literature and then interviewed personnel from prospective user organizations. The survey identified prospective SEASAT users (agencies, institutions and industries), their intended application of the new SEASAT data and the expected areas of economic benefit. The results of the survey, when reviewed with NASA management and the Users Working Group, lead to the selection of six civilian applications case studies:

- Civil Application of an Improved Geoid
- Iceberg Reconnaissance in the Grand Banks Region
- Off-Shore Oil and Natural Gas Production Operations in the North Sea
- Optimum Ship Routing Between U.S. and Japan, for a Selected Cargo Route, and Optimum Routing for Tankers
- Ports, Harbors, and Dockside Operations
- The Sea-Leg of the Trans-Alaska Pipeline

In addition, a case study of military applications was initiated within various activities of the U.S. Navy and was conducted by the Naval Research Laboratory. All six of the civilian applications case studies were completed during this phase of the economic assessment. The military applications case study was initiated during the final two months of this phase and is scheduled for completion during January 1975. Consequently, only very early results of the economic assessment of military benefits were available at the completion of this phase of the economic assessment during June 1974. Table 1.1 summarizes the responsibility and results of the six civilian applications case studies.

Each case study is an in-depth examination of the operating parameters, constraints and structure of a selected maritime operation. These parameters are evaluated for current operations using current knowledge and predictive capability for ocean conditions and the weather, and also for current operations with the improved capability for measurement and prediction of ocean conditions and the weather through SEASAT data. The incremental parameter changes attributable to the use of SEASAT data were then estimated for each case

Table 1.1 Civilian Applications Case Studies

Case Study	Responsibility	Resulting Benefit
1. Civil Applications of an Improved Geoid	Battelle Columbus Laboratories	Computational techniques and measurement accuracy inadequate for geophysical exploration requirements. No benefits developed.
2. Iceberg Reconnaissance in the Grand Banks Region	Battelle Columbus Laboratories	4 hour per ship reduction in transit time during iceberg season.
3. Offshore Oil and Natural Gas Production in the North Sea	Battelle Columbus Laboratories	One year saving for three oil production platforms of about $3.1 million attributed to improved ocean condition forecasts.
4. Optimum Ship Routing	Jet Propulsion Laboratory	2% to 5% improvement in transit time for freighters. Results for tankers incomplete. Potential insurance premium reductions.
5. Ports, Harbors, and Dockside Operations	Jet Propulsion Laboratory	No quantitative information obtained. No benefits developed.
6. Sea-Leg of the Trans-Alaska Pipeline	Ocean Data Systems, Inc.	Improved forecasts and routing yields a maximum of 5.4 additional round trips per tanker per year.

study. These operating parameter increments are the basis of benefits to the operation. The benefits themselves are measurable in constant dollars.

No economic benefits at the present time resulted from the following two civilian case studies:

- Civil Applications of an Improved Geoid
- Ports, Harbors, and Dockside Operations

The case study of Civil Applications of an Improved Geoid sought to establish that the improved geoid would facilitate geophysical exploration through more precise localization of mass anomalies. The present conclusion was reached because available computational techniques do not appear to be adequate to the task of synthesizing gravitational anomalies from the SEASAT altimetry data and its associated geoid and because in geophysical exploration, improvement appears to require an accuracy better than SEASAT capability in order to yield gravity anomalies accurate to the required $\pm$ 0.3 milligals.

In the case of Ports, Harbors and Dockside Operations it was not possible to obtain quantitative information on missed ship ETA's or longshoreman's idle time resulting from inaccurate prediction of ocean conditions and weather. Qualitative opinions on these subjects were obtained, but they were either conflicting or inconclusive. In the absence of the quantitative data needed to perform an economic analysis, no benefits could be developed. The Ports, Harbors and Dockside Operations case study did lead, however, to an understanding of the types of quantitative data required, and it is believed that this data can be obtained in a future study.

Four civilian case studies remain:

- Iceberg Reconnaissance for the Grand Banks Region
- Off-Shore Oil and Natural Gas Production in the North Sea
- Optimum Ship Routing Between U.S. and Japan for Cargo Shipping
- Sea-Leg of the Trans-Alaska Pipeline

For these remaining civilian case studies, economic benefits were developed which were then generalized. In each of these case studies the economic benefits result from an improvement in the efficiency of operations (and also design in the case of off-shore oil and gas production) attributable to improved measurement and forecasting of ocean conditions and weather as a result of SEASAT data. The case study results, assume an accurate sea state and weather prediction capability for a time interval of at least 48 hours and also assume that the appropriate information is well disseminated.

The process of generalization assumes that each selected case study is one of a set of operations with generally similar technical and operational characteristics. If this assumption is valid, a generalization can be performed using appropriate econometric models and economic projections to bound and control generalization.

Generalization of the case studies requires a careful formulation of each case study structure and its parameters that transform SEASAT derived information into economic benefits. Generalization also requires that the class of operations represented by the case study be examined for each member of the class to determine the relationship between information and economic benefits. The process of generalization also requires the extension of the results of the case studies in the dimension of scale (i.e., the relationship of samples to a population), time, (the establishment of a valid planning horizon and forecasting quality variation) and geographical location (for example, extension of results obtained in the North Sea to other geographical sites for off-shore oil production). This requires the construction of appropriate physical models of weather effects and econometric models, and the collection and processing of data for use in these models. The planning horizon for this generalization extended to the year 2000.

Generalizations of the case study dealing with Iceberg Reconnaissance for the Grand Banks Region required a forecast of trade to the year 2000 between the U.S. and Northern Europe. This forecast was derived from the econometric model developed for the Optimum Ship Routing case study. The available data permitted only an estimate of the growth in trade for this particular route in terms of the general expansion of trade and not in terms specific to this route.

The results of this generalization for Iceberg Reconnaissance in the Grand Banks region yielded an expected annual cost savings (1974 $) ranging from $3.7 million in 1985 to $12.1 million in 2000.

The results of a study of the economic impact of ice reconnaissance on Canadian Arctic operations, performed by the Canada Centre for Remote Sensing, were obtained and were incorporated into this economic assessment. This produces benefits based on an assumed growth in exploration and development of the Canadian Arctic through to the end of this century. Benefits associated with ice reconnaissance in the Canadian Arctic were estimated to range from $30.6 million in 1985 to $96.4 million in 2000, measured in 1974 $.

The case study dealing with Off-Shore Oil and Natural Gas Production in the North Sea was based on an analysis of the operating logs of three production platforms over approximately a one year period. The logs were used to determine unnecessary idle time, as a result of inaccurate or unanticipated ocean or weather conditions, for the small ship operations required for pipe laying. These operations require a good weather window of at least 48 hours. Assuming the ability of an operational SEASAT to provide highly accurate 48+ hour forecasts, this unnecessary idle time can be equated to an expected economic benefit. The estimated annual cost savings for the three platforms considered in the case study was $3.1 million (1974 $).

Generalization for the North Sea Field alone entailed estimating the expected oil production from this region to the year 2000. From this oil production estimate the number of production platforms had to be determined based on the daily production capability of a typical production platform. This yielded a North Sea model with sixteen production rigs and 571 miles of pipe, with a total annual benefit in the North Sea of $48.3 million (1974 $).

Global benefits were determined by extrapolating off-shore production to the year 2000, assuming that the 1973 geographical distribution of off-shore production is not significantly changed. The number and geographical distribution of production platforms required to handle this production was then conservatively estimated using a maximum production rate of 100,000 bbls/day per platform. (It should be noted that platform production typically ranges from 20,000 to 100,000 bbls/day.) Weather effects on production were estimated from the frequency of winds in each production region equal to or greater than Beaufort 7, which limits small ship use. The results of this generalization indicate an annual global benefit from improved forecasting of ocean and weather conditions to off-shore oil and natural gas production in the range of $86 million to $214 million (1974$).

More precise evaluation of these benefits requires an economic interpretation of the growth of exploitation in off-shore oil production, development and exploration. This growth is evidently dependent on the worldwide demand for oil, the price of oil and the requisite production to oil reserves ratios desired in each off-shore oil field. The mechanisms by which cost reductions are produced in each of these operations will have to be determined for appropriate weather and sea state forecasting quality.

A careful evaluation of the application and implementation of contemporary technology to rig and platform design will also be required. This technology will be specifically applied to operating structures in violent or icebound sea and weather conditions and is expected to influence operating cost savings.

These evaluations with the help of user groups will be made during the next phase of this economic assessment.

To generalize Optimum Ship Routing, a model was constructed to derive the worldwide demand for shipping from an analysis of trade flows by commodity and by route. However, data limitations constrained the generalization to trading across the North Atlantic and the Pacific between the U.S. and its ten principal trading partners. Thus the initial case study of twenty-one crossings of the North Pacific was expanded to consider a broader trade sector. While U.S. trade accounts for about 18% of world trade, the trade sector of the generalization accounts for only about 10% of world trade. The remaining U.S. trade (8%) occurs on routes operating in a relatively benign ocean environment where improved ocean condition forecasts will have a smaller economic impact. Excluding this 8% of global trade, the annual U.S. benefits for selected years is given in 1974 $ as:

1987	$33.7 million
1992	$38.1 million
1997	$42.5 million

The achievement of this benefit requires the assumption that the utilization of improved ocean condition and weather forecasts derived from SEASAT data is available and accepted by the leading maritime nations, as the bulk of trade with the U.S. is conducted in non-U.S. ships. If this assumption is valid, then the global benefits will be larger than those stated above.

The generalization of the Sea-Leg of the Trans-Alaska Pipeline required modeling of the route from Valdez, Alaska to the U.S. West Coast. This entailed the modeling of a marine transport link with one origin, multiple destinations, a dedicated fleet of ships with varying capacities, and storage capacity at the origin and destinations. The model was formulated as a linear programming problem which was solved by the integer programming method.

The results for an optimized system indicate an operating cost of approximately $400 million per annum (1974$) for the movement of the oil. This figure pertains to the newly defined 35 tanker fleet for which the tanker distribution to U.S. West Coast ports is not available from Alyeska. Without this tanker distribution it is not possible to determine the non optimized system operating costs and thus to determine the savings achievable by appropriate scheduling.

Earlier computations performed for the 41 tanker fleet indicated that scheduling optimization reduce the fleet annual operating costs from $256 million approximately to $200 million, a saving of $56 million (1974$).

An additional $9.4 million per year, with the 35 tanker fleet, could initially be saved through full utilization of improved ocean condition and weather forecasts derived from SEASAT data. This savings will vanish by the year 2000 under the assumption that the North Slope Oil Fields will be depleted by the year 2002 based on the estimated known oil reserves.

Table 1.2 summarizes the lower bound of the generalizations of the benefits of SEASAT. This table was constructed by summing the discounted annual value of the expected benefits (1974$) over a planning horizon extending from 1974 (FY 1975) through 2000. Discount rates of 5%, 10%, and 15% were used to illustrate the sensitivity of the expected benefits to discount rate. It should be noted that most of the benefits are associated with the operational SEASAT system, and that these benefits commence in 1985. Discounting these benefits to 1974 significantly reduces their present value. The present value of the partial aggregate benefits ranges from $352 million (15%) to $1,512 million (5%).

Where benefits were determined to have a range of estimation, the lower value of the range is given in Table 1.2; Table 1.3 indicates the upper bound of the range. Both estimates are conservative.

The estimation of military benefits is preliminary and incomplete. Additionally, several promising and application areas suggested by user contact, such as the ocean fishing fishing industry and the design and monitoring of off-shore nuclear power plants could not be investigated during this phase of the economic assessment with the time and resources available. Thus, this preliminary assessment of SEASAT

Table 1.2 Lower Present Value (1974 $) of Partial Aggregate Benefits (Millions of dollars)

Benefit Source	Benefit Lower Bound Discount Rate		
	5%	10%	15%
Optimum Ship Routing (U.S. Trade)	243	110	52
Iceberg Reconnaissance	24	11	6
Canadian Arctic Operations	595	270	138
Sea-Leg of Trans-Alaska Pipeline	26	13	7
Off-Shore Oil Production	580	264	130
Military Applications	44	28	19
TOTAL	1512	696	352

Table 1.3 Upper Present Value (1974 $) of Partial Aggregate Benefits (Millions of dollars)

Benefit Source	Benefit Upper Bound Discount Rate		
	5%	10%	15%
Optimum Ship Routing (U.S. Trade)	243	110	52
Iceberg Reconnaissance	78	36	20
Canadian Arctic Operations	959	435	223
Sea-Leg of Trans-Alaska Pipeline	26	13	7
Off-Shore Oil Production	1450	660	325
Military Applications	44	28	19
TOTAL	2800	1282	646

economic benefits is only a partial accounting of expected benefits. It is fully expected that the continued economic assessment will define additional significant benefit areas.

The benefits derived from two case studies viz: for military applications and for the Sea-Leg of the Trans-Alaska Pipeline, constitute clear national benefits. The benefits derived from the other case studies however, are global or international in character.

Of the global benefits only those derived for Iceberg Reconnaissance have an established mechanism for dissemination and insertion into maritime operations. This established mechanism is the International Ice Patrol (IIP), and SEASAT derived data would essentially be a supplement to current operating procedures of the IIP. Formal acceptance of SEASAT supplemental information may, it is estimated, take as much as five years of learning. Once accepted, a formal procedure exists within the IIP to assess ship tonnage for the use of the service and to thereby defray the expense of the service implementation.

The other global benefits can only be realized provided that effective procedures are established through which a diversity of maritime and marine operations can participate in the SEASAT derived outputs and acquire the learning essential to full use of SEASAT data and to the associated improvement in productivity of capital and labor.

In Section 3.4 it is argued that U.S. policy should function to make SEASAT information widely disseminated and easily available since then both U.S. prestige and the U.S. economy can be expected to maximally benefit.

If the U.S. seeks to act as an agent to supply the SEASAT derived data for a fee, then a number of implementation problems will require solution. This implementation will take the form of agreements which will relate the service supplied to the fee for the service.

2.0 INTRODUCTION

The objectives of the SEASAT program are to provide scientific and economic benefits by the remote sensing of global ocean dynamics and physical characteristics.

SEASAT-A is planned for launching in 1978 and will be a proof-of-concept program which will demonstrate and evaluate a system consisting of the spacecraft, instrument payload, and data acquisition, processing and dissemination systems. It is intended that the following step, SEASAT-B, will be a demonstration of a prototype operational system for monitoring the marine environment. SEASAT-B will provide the basic data needed for predicting this environment and for developing and improving user services such as sea state and temperature analysis and forecasts, minimum time ship routes, and ice warnings. Current planning and forecasts of technical capabilities indicate that a fully operational SEASAT system could be achieved not later than 1985. Once an operational SEASAT system is achieved, it is assumed that continuity of data as required by operational users of the system will be maintained.

The satellite instrumentation, its associated data processing, data integration, data accessing and dissemination subsystems, together with all necessary supporting subsystems, will be developed in an integrated manner to produce and provide synoptic, dynamic, global forecasts of the sea-atmosphere interface to a broad range of users. The data will measure the state of the surface of the sea and determine surface wind indirectly.

It is an implicit assumption that the quality and updating frequency of the dynamic forecasting information will create an opportunity to improve the efficiency with which maritime operations, both national and international, can be conducted. The operations to be considered are the maritime transportation of resources, both natural and produced, and those in which the sea surface is used to locate equipment to interact with the earth's crust below the sea surface for the exploitation of natural resources.

It is the purpose of this report to both explain and quantify the improvements in efficiency of maritime operations that result from the existence of SEASAT. The measure of quantification to be employed is that of the standardized constant dollar or real value of the efficiency improvement, subsequently described as SEASAT benefits.

Maritime operational hazards have existed from the beginnings of trade. Today new forms of maritime operations are evolving. In these new forms of maritime operations technology and regulation has been concentrated on improving the economic, ecological, and social environments rather than the physical environment. SEASAT will concentrate on improving the maritime operational interface with this physical environment. SEASAT will, therefore, be complementary to current processes which tend to define maritime operations as integrated systems and to seek optimized operating conditions, in terms pertinent to the operators.

Today's maritime operations are all constrained in efficiency by unpredictable or unavoidable variations in the sea state or the sea condition. If the sea state variations of significance to a maritime operation can be predicted with appropriate quality and forecasting interval, then a potential operational efficiency improvement will exist. To capture this potential or to produce operationally effective efficiency requires SEASAT data to be processed into information, the dissemination of the information, and that the information be acted upon and integrated into the operations. In some circumstances, this integration or implementation may be delayed or may not occur fully because it is contingent on the resolution of other problems that exist within the context of the operations being considered.

The benefit from efficiency improvement in operations, potential or captured, is measurable as a constant dollar equivalent value. A summation of all such benefits appropriately discounted would be a quantitative indicator of the impact or amplification of SEASAT's research, investment, and operating costs within a generalized economic system, either national or international.

SEASAT's benefits can then either result in less resources being necessary to conduct the same operations or they can be translated into an increased operational capacity, or some combination of these.

In the former case, operational resources can truly be conserved only if the planning of the operations includes SEASAT output capability. This requires a clear, assured indication of SEASAT performance and a procedure for dissemination of SEASAT information. In the latter case, the benefits are effective only if the consequences of increased operational capacity are necessary in the sense that they can be utilized or absorbed by the generalized economy without unduly influencing the descriptive parameters of the generalized economy.

Captured benefits are therefore dependent on assumptions about conditions within the context in which the potential benefits will exist.

In a general analysis in which benefits are defined and quantified as a range of dollar values, the benefits remain unassociated beyond the fact that they will reside in the operation from which they were derived. In a program such as SEASAT which will employ public funds, the benefit of most significance will be the captured social benefit. This is the benefit which will be captured by society in general, rather than by a special interest group such as the one responsible for the maritime operation being considered.

Determination of the captured social benefit can be attempted through a judgmental interpretation of the economics of an operation based on accepted economic theory to assess the fraction of the captured benefit that may be returned to society. The process, however, involves a large number of intermediate interfaces such as ship owners and operators, or oil exploration consortia, and society in general. At each of these intermediate interfaces there is the opportunity for many alternative decisions relative to the disposition of benefits and without further study there is little basis for choice amongst these alternatives. For these reasons, social benefits were not estimated in this economic assessment.

As a procedure, determination of SEASAT's benefits requires an initial assessment of the interaction between SEASAT's outputs and the various forms of maritime operations. The maritime operations must be considered in the context of their own technical, environmental, economic, and operating constraints. The assessment is performed through the selection of a set of case studies in which particularized and apparently advantageous operations are studied in-depth. From the case studies, specific benefits are developed.

Insofar that the studies are representative of general classes of operations, or can be reasonably interpreted to be so representative, the case study benefits can be generalized into the future. At the same time, the generalization context in which these operations will occur must also be considered and predicted.

It is evident that a case study's particularized benefits involve less estimation risk than its associated generalized benefit, most significantly because the basic data of the case study is more concrete than that of the generalization. The benefits of the case studies and the generalizations must also be separated into national and non-national benefits if benefits are to be allocated on a national basis. With maritime operations, this requires an understanding and economic interpretation of the nation's export-import trade with the rest of the world and also economic assumptions about the amount of that trade that will be captured by U.S. owned and operated vessels. In addition, SEASAT may have a major interface with crude oil operations. The rapid and continued growth in international maritime crude oil movement has now consolidated it as the largest single world trade element in volume (55%) and in value (10%). Furthermore, there is a considerable expansion in the exploitation, development, and production of oil and natural gas from pools located beneath the sea whose efficiency of operation is dependent on sea state conditions. Interpretations of benefits that can result requires an understanding of the economics of exploration, production, and transportation of crude oil and natural gas, projected into the future.

To illustrate the different influences of SEASAT's instrumentation on the production of benefits, an attempt has been made to relate the technological dependence of the benefits determined. Certain benefits are associated with SEASAT-A, generally those captured by DOD. The remaining benefits are associated with the operational SEASAT system and in some instances require specific instrumentation performance.

The case studies selected address both civilian and military applications. The preliminary estimate of military applications was conducted under the direction of the Naval Research Laboratory. A more detailed study of military applications and their benefits has been initiated and is scheduled for completion in 1975. Six case studies in the civilian sector of the economy were undertaken:

1. Optimum Ship Routing
2. Iceberg Reconnaisance
3. Ports and Harbours
4. The Sea Leg of the Trans-Alaska Pipeline
5. Civilian Uses of the Improved Geoid
6. Rig and Pipe Laying Operations in the North Sea

These case studies, the process of their generalization, and their integration into an Economic Assessment of the SEASAT program are described in this report.

3.0 THE SEASAT SYSTEM

3.1 Description of SEASAT-A

3.1.1 Introduction

The SEASAT-A spacecraft will be launched in CY 1978 into a circular, 108° inclination orbit with an altitude of approximately 800 km. During its planned minimum operational life time of one year the spacecraft will fly a set of earth viewing sensors operating primarily in the microwave region of the spectrum. These sensors will produce data relative to sea state, sea surface topography, wave directional spectra, sea surface winds and direction, temperature, ice cover, and geoidal variations. The major difference between SEASAT-A and previous earth observation satellites is the capability for all weather observations through the use of active and passive microwave sensors.

SEASAT-A is planned as a proof-of-concept program which will demonstrate and evaluate a system consisting of the spacecraft, instrument payload, and data acquisition, processing and dissemination systems. It is intended that the following step, SEASAT-B, will be a demonstration of a prototype operational system for monitoring the marine environment. SEASAT-B, will provide the basic data needed for predicting this environment and for developing and improving user services such as sea state and temperature analysis and forecasts, minimum time ship routes, and iceberg warnings.

3.1.2 Objectives

The objectives of SEASAT-A are to demonstrate a capability to measure global ocean dynamics and physical characteristics, provide data for user applications, demonstrate the key features of an operational system, and determine the economic and social benefits of user-organization products and services.

The specific objectives of SEASAT-A are to:

1. Demonstrate a capability for

   Global monitoring of wave height and directional spectrum, surface winds, ocean temperature, and current patterns

   Measuring precise sea-surface topography; detecting currents, tides, storm surges, and tsunamis

   Charting ice fields and leads

   Mapping the global ocean geoid

2. Provide data for user applications

   Predictions of wave height, directional specturm, and wind fields for ship routing, ship design, storm damage avoidance, coastal-disaster warning, coastal protection and development, deep-water port development, offshore power plant siting

   Maps of current patterns and temperature ship routing, fishing, pollution dispersion, iceberg hazard avoidance

   Charts of ice fields and leads for navigation and weather prediction

   Ocean geoid find structure

3. Demonstrate the key features of an operational system

   Global sampling

   Near-real-time data processing and dissemination

   User feedback for operational programming

4. Demonstrate economic and social benefits of user-agency products

While many of these objectives are achievable by the successful acquisition of quality oceanic data by SEASAT-A, it will be necessary to have the commitment and close cooperation of interested user organizations in order to derive the full economic and scientific benefits from the data obtained by the spacecraft system.

3.1.3 Mission

The satellite will be launched and injected into a high inclination circular orbit (eccentricity $\leq$ .006) from the USAF Western Test Range. The launch date will be during the first half of calendar year 1978. The orbital altitude will be approximately 800 km, to be determined by compromises between sensor resolution, power, size, and coverage. The orbit of 108° inclination will be designed to provide 36-hour repeat coverage globally in consonance with a 1000 km cross-track surface coverage. This includes front and back orbit data collection to achieve the necessary repeatability. Orbit selection will also take into account desires to maximize telemetry and tracking coverage. The capability to acquire and disseminate data in near-real-time (less than three hours delay) will be demonstrated on a limited basis. The program shall provide for the launch of one spacecraft on the scheduled date, plus the capability to launch a backup spacecraft within 18 months in the case of a catastrophic failure. The spacecraft and sensor design lifetime is one year. However, system expendables will be sized for three years of life.

The ground support includes the capability for real-time spacecraft health evaluation; spacecraft command and control; in-depth evaluation of the acquired data by the experimenters for future planning of the operation of experiments; and a data management system that provides timely data handling, processing, and distribution to the investigators. A real-time mode of data handling and dissemination, with a delay of three hours or less, is possible on a limited operational demonstration basis.

The mission operations will be planned for a nominal one year duration, with at least one tracking and real-time telemetry pass per orbit, and one "command" pass per day for reprogramming the on-board computer. The data processing requirements will be primarily for non-real time data package production, with an occasional short term real-time data processing capability for demonstration purposes.

The Mission Operations Control Center will share the existing AE/OSO facility and the Sigma-9 processor which will be used to transform satellite telemetry into user-compatible data packages.

The STDN tracking and data acquisition will be used to provide baseline tracking and S-band telemetry and command functions.

The NASA Laser Tracking Network will provide precise tracking when satellite viewing permits.

A terminal facility for distribution of some data, and for communication with selected users will be available on a time-sharing basis within the existing AE/OSO facilities capability.

Participation of the Department of Defense TRANET facilities will be determined and specified.

The SEASAT-A Project Operations Control Center (POCC) is the focal point for all project-unique mission operations, beginning with the pre-launch simulations and continuing throughout the mission-support lifetime.

3.1.4 Sensors

The basic measurement objectives of the SEASAT-A program will be met by a combination of active and passive microwave sensors, assisted by a visible and infrared imagers.

Alternative sensor complements are being considered for SEASAT-A as a function of cost and schedule consistent with a selected mission. The candidate sensors are described in the following paragraphs.

The baseline mission for SEASAT-A will include all five candidate sensors, while the alternative mission does not include the Synthetic Aperture Coherent Imaging Radar.

Figure 3.1 illustrates the relationship between the sensors, measurements, and the physical parameter of the desired ocean condition. As shown in Figure 3.1., a multiplicity of sensors and measurements are required to yield the physical parameters of the ocean conditions.

3.1.4.1 Compressed Pulse Precision Radar Altimeter

This sensor has two distinct functions. The first is to meet an objective of $\pm$ 10 cm precision in altitude measurements. The altitude measurements will be used in conjunction with accurate orbit observations to determine the topography of the sea surface. The topography may in turn be related to the geoid, currents, deep ocean tides, storm surges, etc. An altitude precision of $\pm$10 cm will require water vapor, liquid water and dry atmospheric corrections to the pulse delay time. Second, the broadening of the short, compressed pulse due to surface waves is used to determine the significant wave height along the sub-satellite track. The objective of $\pm$50 cm in wave height precision requires a compressed pulse length of the order of 3 ns. The altimeter will draw upon SKYLAB and GEOS-C experience with such instruments, which operate at 13.9 GHz.

3.1.4.2 Five Frequency Scanning Microwave Radiometer

The objective of this instrument is to provide measurements of wind speeds ($\gtrsim$ 10 m/s with a precision of $\pm$ 2 m/s), sea surface temperature with a precision of $\pm$ 1.5°K, and water vapor and liquid water corrections to the altimeter.

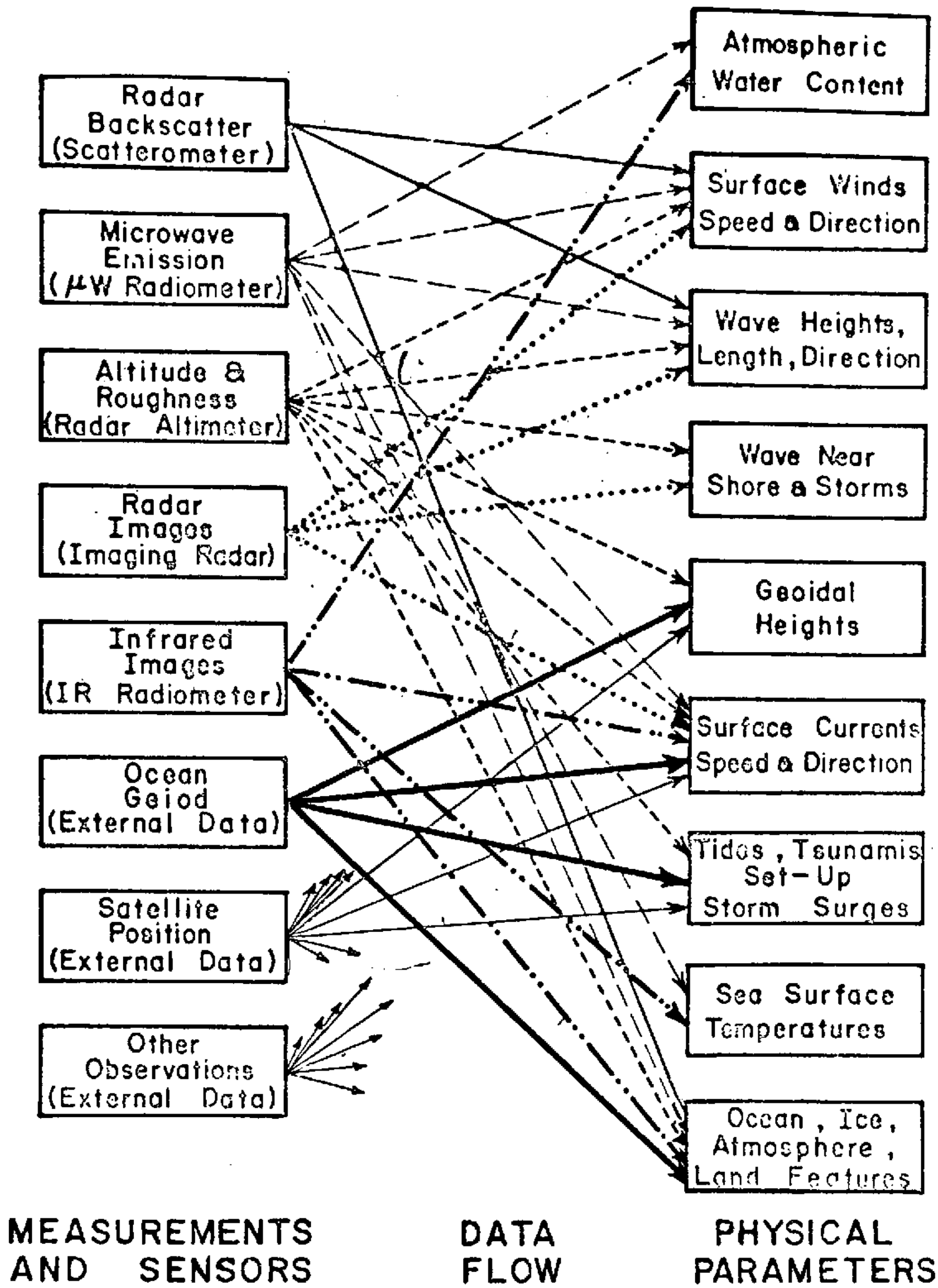

Figure 3.1 Instrumentation Data Flows Required to Produce Sea Surface State Information.

This instrument may also produce relatively low resolution images of sea ice coverage since it measures the microwave brightness of those targets in its field of view. For the wind speed measurements the foam that wind generates, being of higher emissivity than the undisturbed water, yields a microwave signal that increases with increasing wind speed. In the case of sea temperature, warmer water is brighter than cold in the low microwave frequency region. The signal due to either wind or temperature is contaminated by changes in the other variable and by water vapor and liquid water in the intervening atmosphere, and hence corrections to each variable are necessary due to the presence of all others.

The operating frequencies for the radiometer are 6.6, 10.7, 18, 22 and 37 GHz. An earth incidence angle of 55°, a cross-track scan of ± 20°, and an instantaneous field of view of less than 100 km are required. With these choices, near-all-weather determinations of wind speed and temperature appear possible over a swath width of approximately 1000 km.

3.1.4.3 Microwave Wind Scatterometer

The objective of this device is to measure wind speeds, ≤ 25 m/s with a precision of ± 2 m/s. It functions by illuminating the sea with 13.9 GHz microwave energy at off nadir angles between about 15° and 50°; small capillary waves, which are intimately associated with the instantaneous wind, then scatter some of this signal back to the receiver. The behavior and level of the scattered energy may be used to infer winds whose speeds range up to approximately 15 m/s. Some directional information may be obtained as well. A swath width of up to 1000 km and a resolution of 20-50 km appear possible. The SKYLAB scatterometer will guide the design of this device.

3.1.4.4 Synthetic Aperture Coherent Imaging Radar

The imaging radar has two well understood functions and several experimental roles. The objective of this instrument is to provide all-weather images of waves and ice fields, taken in the illumination of a coherent microwave signal, with a resolution approaching 25 m. Using these images it may be possible to derive wave directional spectra, wave refraction patterns near shorelines, jetties, and off-shore structures, sea state forecasts, and ice leads and cover. The instrument has potential capabilities as a precision altimeter, as a wind scatterometer, and as a device for measuring significant wave height. Experiments will be necessary to assay those capabilities of the instrument. Indicated microwave wavelengths of 3, 25, and 200 cm are being investigated. A swath width of 100 km located a few degrees off nadir appears possible. The coherent radar flown on APOLLO 17 will provide much guidance to the design of this sensor.

3.1.4.5 Visible-Infrared Scanning Radiometer

The objective of this instrument is to provide data for the visual identification of oceanic and atmospheric features and to aid in the interpretation of the various microwave signals from the other sensors. Currents, clouds, storm systems and ice are features of interest. The preferred wavelengths are 6000-9000 Å and 10.5-12.5μm, and an instantaneous field of view of 7.5 km or less is acceptable for recorded data with horizon-to-horizon scan required.

3.1.5 Spacecraft and Launch Vehicle

Alternative spacecraft and launch vehicle configuration are presently being considered in the Mission

Definitions Studies. General performance requirements for both the spacecraft and launch vehicles have been established by previous studies.*

The spacecraft design emphasizes existing subsystem hardware or design and requires no new technology. The total weight is approximately 1000 kg; the total power requirement, including sensors, will be approximately 400 watts and will be supplied by solar cell arrays; 300 watts are allocated to sensor systems. The attitude control system will be earth-centered, and three axis-stabilized with a pointing accuracy of $\pm$ 0.5°, and post-analysis pointing knowledge of $\pm$ 0.2°.

The satellite data system will include: conventional tape recorder storage capability of approximatley 2×10^9 bits; record/playback rates up to 2 Mb/s; data telemetry rates of 25 Kb/s average, with up to 5 Mb/s occasionally required to support the coherent imaging radar in real time. A general purpose processor will be integrated into the system for sensor and satellite control and management of data processing functions. Tracking systems will include S-band and doppler systems and laser reflectors.

The launch vehicle for SEASAT-A will have an injection capability >1500 kg for an 800 km circular high inclination orbit, dependent upon exact vehicle configuration, and launch vehicle selection. Launch will be from the Western Test Range.

3.1.6 User and Data Utilization

The SEASAT-A requirements have evolved through the active formalized participation of the interested user community in a SEASAT User Working Group. The function and

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* SEASAT-A Study Task Team Report, October 1973, NASA.

operation of the User Working Group within the context of the SEASAT-A activities is described in Section 4.1. The user community from which the User Working Group has been drawn includes.

Government

Department of Commerce -	National Oceanic and Atmospheric Administration
	Maritime Administration
Department of Defense -	Director of Defense Research and Engineering
	Naval Research Laboratory
	Defense Mapping Agency
	Naval Weapons Center
	Fleet Numerical Weather Center
	Naval Oceanographic Office
	Coastal Engineering Research Center
	Corps of Engineers
Agencies	Department of Interior
	Geological Survey
	Department of Transportation
	Coast Guard
	Atomic Energy Commission
	Environmental Protection Agency
	National Science Foundation
	National Aeronautics and Space Administration
	National Academy of Sciences
	National Academy of Engineering

Institutions

	Smithsonian Astrophysical Observatory
	Woods Hole Oceanographic Institution

Scripps Institution of Oceanography/
University of California
University Institute of Oceanography/
City College of New York
Battelle Institute

Private Sector

American Institute of Merchant
Shipping
American Petroleum Institute
Sea Use Council

Data analysis activities funded and provided by NASA for SEASAT-A will be proof-of-concept oriented, and as such, will consider data samples for detailed processing to validate system performance. Large scale data analysis required by the user community will be funded and performed in the interested organizations.

Figure 3.2 is a tentative listing of the planned use of SEASAT-A data products by a part of the SEASAT-A user community. It is considered that additional uses, including specific investigations of a scientific nature as well as operational demonstrations, will be evolved by NASA and the user community prior to the planned launch of SEASAT-A.

3.2 Operational System Capabilities

The operational SEASAT will generate information, which when combined appropriately with information from other sources, will provide accurate 48^{+} hour forecast of the global sea state and weather.

An accurate forecast will have a probability of being correct, which is greater than 0.5 with an objective of a probability between 0.8 and 0.9. This is in contrast with current capability, which is approximately 0.2.

- **DEPARTMENT OF COMMERCE**

  NOAA:

  National Weather Service: Experimental Wind, Wave Forecasts, Ice Observations

  National Environmental Satellite Service: Spacecraft Oceanography Technology

  National Ocean Survey: Geodesy, Mapping

  Environmental Research Laboratories: Wave Propagation Near Storms, Tsunamis, Storm Surge, Tides, Currents, Sea-Air Interaction

  MARAD: Optimum Ship Routing; Ship Design

- **DEPARTMENT OF DEFENSE**

  Defense Mapping Agency: Geodesy, Sea Surface Topography

  Naval Research Laboratory: Microwave Interactions with Sea, Information Analysis, Data Dissemination, Sea Topography

  Naval Oceanographic Office: Surface Wind, Wave Height and Spectra, Sea Surface Temperature, Topography, Coastal Processes, Polar Oceanography

  Naval Weapons Laboratory: Geodesy, Sea Surface Topography

  Fleet Numerical Weather Center: Operational Analyses, Sea Temperature, State, Winds

  Environmental Prediction Research Facility: Data Analysis, Information Dissemination, Support Products and Services

  Office of Naval Research: Basic and Applied Oceanographic Research

  Corps of Engineers: Coastal Processes

- **DEPARTMENT OF TRANSPORTATION**

  Coast Guard: Ice Surveillance; Oceanographic Research

Figure 3.2 Utilization of SEASAT-A Data

This capability is postulated on the assumption that existing mathematical descriptions of the ocean atmospheric coupling in terms of heat and momentum exchange, the state variables within both fluids and at their interface and regional predictive equations are only constrained by lack of observational data. By 1985, the required observational data, it is assumed will become available primarily from satellite collecting, data handling and communications systems, in which the operational SEASAT will play a role.

A detailed description of the systems design, configuration, resources, and schedule necessary to provide these capabilities is not available, and indeed the programmatic and economic analyses and assessments required to understand these tasks has not been developed. However, the following description can be used as an initial condition to evaluate the utility of the operational SEASAT system. The data gathering capability of the operational SEASAT is assumed to be "all-weather".

3.2.1 Operational Modes and Data Output

Systems capabilities are described at the data output interface in terms of three operational modes.

3.2.1.1 Oceanographic Data Services

Oceanographic data would be available on a near real-time ($<$ 2hrs. delay from real-time) basis. Full global coverage of all measurements will occur every 24 hrs. (at the equator and more frequently at higher latitudes). It is assumed that these types of data would be accepted, processed, and provided by institutional sources such as the Navy's Fleet Numerical Service at Monterey, California, NOAA's weather processing center at

Suitland, Maryland, and the Coast Guard Data Center at Kings Point, Long Island, New York. A satellite system would probably be the major, but no exclusive, source of data. Other data may be provided by sources such as aircraft, ships, buoys, and ballons. Data to be provided will include the following.

3.2.1.1.1 <u>Waves</u>

An energy density spectrum (density of selected wave spectral intervals) frequency vs. amplitude will be provided. This will include fifteen spectral intervals of waves between 50m and 700m length. On spectrum will be obtained for each 24 hour interval for a 50km x 50km grid area, globally. In addition, 18 directional intervals of wave movement (without ambiguity) will be furnished.

3.2.1.1.2 <u>Winds</u>

Wind velocity will be obtained from 3m/sec to 50m/sec (at an accuracy of $\pm$ 1m/sec or 10%, whichever is larger) averaged over 100km x 100km grid in the open ocean, and 10km x 10km grid in selective areas such as coastal of shelf areas. The basic resolution cell size globally would be 5km x 5km. Eighteen direction intervals would be used and ambiguity is acceptable.

3.2.1.1.3 <u>Temperature</u>

All weather temperature maps of the global ocean, average over 50km x 50km grid areas to $\pm$ 1°C absolute of 1/2°C relative accuracy, will be provided.

3.2.1.1.4 Feature of Interest Mapping

- Ice Field Mapping. Maps of northern latitude areas of ice environment, including the Great Lakes, showing ice, leads, open water, large berg location, drift rate, and direction will be obtained.
- Pollution Area Definition. Oil spill and other effluents, their propagation, area, and concentration will be mapped.
- Major Storms. Geophysical description of the most important storm parameters (wind, wave height, surge), and estimates of their effect on surrounding geographic areas will be obtained.

3.2.1.2 Direction Satellite Read-Out

Directo read-out information will be avaiable to users, such as ships, fisheries, coastal and offshore construction sites, when the user is in range of a data read out satellite and equipped with low cost VHF and UHF receiver capability. Implementation of such a capability could be achieved in numerous ways, and additional study of operational system designs will consider these and other system design requirements. At this time, it is assumed that open ocean and coastal areas of high commercial activity could receive a grid of information accessed by geographic preference upon demand. Each grid would be approximately 230km x 230km in the open ocean, and 50km x 50km in coastal zones, and would contain a synoptic description of conditions in that zone having to do with sea conditions (swell, chop length of waves, wave height, direction. etc.) wind magnitude, direction and duration history, temperature and salinity as well as data from other sources having to do with atmospheric conditions. Data refresh in this stored descriptive grid would be based on a floating aperture limit program with averaging times as a function of the nominal time constant of change for each characteristic of interest. For example, temperature normally has a more leisurely change pattern than wave conditions. The program would also have alarm limits (based on nominal history of conditions over broad periods of time, one month - two months, or historic values dependent on expected seasonal variations) which if exceeded would produce highlighted data on the grid area of interest relative to hazard warnings, or other event notifications.

3.2.1.3 Conversational Retrieval and Analysis

This mode of operation would be available on demand within a planned service capability (probably via one or more of the user service facilities) for use by scientific and other investigative interests. The basic satellite and other source data being sent to the processing centers in its more detailed form (unprocessed into averaged synoptic data) would be held in file for a period consistent with the library size (perhaps 30 to 60 days) and could be called up and copied for or processed by the scientific user. Table 3.1 specifies the content of the available data. Imaging Radar surveys of areas of specific interest will have to be prior specified and commanded.

3.3 Data Dissemination and System Interfaces

3.3.1 Introduction

The observational data needs for the operational system are extensive, sub-dividing the earth's surface into a one-square-degree grid within which 20-25 vertical measurements in the atmosphere will be required and 10 vertical measurements in the ocean. The measurements are of the state variables:

Table 3.1 Content of Available Data

Measurement	Precision Accuracy	Resolution	Grid Size
Sea State H 1/3 Wave Ht. 1 to 20m	± 1m or 25% * ± 5m **	20km MAX.	20km MAX.
All Weather Temperature -2 to + 35°C	± 1° Absolute ± 1/2° Relative	1 to 100km	50 to 100km
Wave Directional Spectrum $\lambda = > 50$ m, $\Theta = 360°$	Wave Height ± 1/2 To 1m or 25% $\lambda \pm < 20\%$, $\Theta \pm < 10°$	50m x 50m	400km Swath
Sea Surface Topography Including Marine Geoid	± 10cm Vertical	10km	10km Along Track
Integrated Atmospheric Water Vapor	Altimeter Error Contribution ± 5cm	10km Desired	Nadir Column
Atmospheric and Ocean Features	Temperature ± 1/2°C Relative	100 to 500 m	Swath 1200km
Surface Winds	0 - 50 m/s ± 2 m/s or 10% Direction ± 10°	50km to 100km	50km to 100km ± 1200km Swath
Surface Images		10m Mode I 30m Mode II	50km Swath 200km Swath

* Department of Commerce
** Department of Defense

pressure, temperature, wind, and moisture. To achieve global synoptic forecasts of the weather and the sea state, this composition of observational data must be evaluated at regional centres from and to which, via Communication Satellites, will be sent regional predictive solutions as initializing conditions. Global data should be amassed in one or two hours. The computer performance necessary to solve the describing system of partial differential equations and its auxiliary set of ordinary differential and algebraic equations, by appropriate integration, is estimated to be 108 instructions per second, a capacity projected to be available in the period 1978-82.

The computer processing for the data, particularly for the SEASAT contribution, must be structured according to the operational development of the satellite, but it is expected that appropriate computer capacity will be available also in 1978-82.

3.3.2 The Dissemination of Information Derived From SEASAT Data

As noted in Sections 3.2 and 3.3, SEASAT will produce data and information which describes the sea-atmosphere interface, in particular, the activities in this interface that are of a nongravitational origin; namely topography and ocean conditions.

This input, when suitably combined in computer models with data and information from many other sources, including non-U.S. sources, will result in a global predictive capacity combining weather and sea state expected observables.

For benefits of any type to emerge from application of these expected observables, the observables must be processed and then appropriately disseminated with proven regularity and with proven accuracy to users. The accuracy is most likely to be proven by comparison of SEASAT's predicted observables with actual observables recorded at sea (sea truth).

Dissemination with regularity is primarily a problem in communications, generally amongst institutions.

If it is assumed that any information distribution system created will be exclusive to the U.S., then it is possible to reflect on the dissemination options that the U.S. may retain. It is, of course, not clear that this informational system will be U.S. exclusive, because of the international nature of maritime operations, and because the real power of an operational SEASAT seems clearly resident in its international appeal.

Any attempt by the U.S. to restrict SEASAT-type information would, it is conjectured, result from concepts of advantage or self-preservation. The former would be most clearly seen as an economic advantage, the latter in terms of national defense. Since the operations of national defense, in all phases of peace and war, have a strong dependence on weather ocean conditions prediction, national defense cannot be postulated on the existence of a single such predictive system. National defense operations must be supported by redundancy in the supply of intelligence, tactical and strategic, which is where SEASAT's information would lie. Therefore, national defense objectives would be most realistically postulated in a model using SEASAT as one of the many inputs rather than as a prime system, except perhaps for geoid data derived from the altimetry measurements.

Dissemination restriction, therefore, could be selected for advantages in economic operations only, and the economic advantages must clearly contribute to the U.S. competitive position in world markets.

Improved forecasting of ocean conditions, when combined with other data, can lead to improvement in the forecast of weather over land. Economic benefits derived from

SEASAT data can occur, therefore, on land and sea. Since most activity of an economic nature is conducted on land, the benefits from improved forecasting of weather on land accruing to agriculture, construction activities, and transportation promise to vastly surpass the benefits accruing to economic activities on the sea (e.g., shipping, fisheries, oil and gas exploration, and extraction). However, the present analysis is limited to the latter class of benefits. The economic benefits will result essentially from increases in the productivity of labor and capital (e.g., ships, cargoes, drilling platforms, etc.).

If SEASAT data were available only to U.S. business firms, they should, in principle, enjoy a corresponding advantage over their foreign competitors. There are, however, three direct countervailing considerations. One relates to the difficulty of disentangling American from foreign business interests, the second to certain costs (if not sheer impracticability) of restricted dissemination, and the third to the benefits of unrestricted dissemination. In short, whether the United States should disclose SEASAT data broadly or not depends on the monopolist value of U.S. business use

<u>minus</u>

a. a discount derived from the difficulties and costs of effectively restricting information to U.S. business users;

b. the benefits of unrestricted dissemination.

A close study of the problems of disentangling U.S. from foreign business interests has not been undertaken. The nature of the problem is, however, fairly clear. American firms do not only own and operate ships sailing under the American flag, but also ships sailing under foreign flags (especially Liberian and Panamanian). American firms also charter foreign-owned ships. Furthermore, offshore drilling is frequently undertaken by consortia formed by foreign and U.S. oil companies.

But even if one could distinguish U.S. from non-U.S. business interests, restricting the flow of information to the former would generate additional difficulties and costs. It is obviously not easy to restrict forecasts on weather and the state of the sea, and ship routings based thereon, to U.S. business recipients. And, even if this were done, it would be difficult to prevent dissemination, deliberate or involuntary, by the recipients to foreign users. The larger the number of legitimate recipients, the greater would be the probability that the information would leak. It is, of course, impossible to quantify the discount attributable to these difficulties and costs. But, it should not be ignored unless it is apparent that the monopolist value of restricted dissemination to American business is large on all other grounds.

United States benefits from broad or unrestricted dissemination of SEASAT data are several. First, the United States would presumably share in the productivity gains achieved by foreign producers. Precisely who captures these gains depends on many complex conditions, including notably the degree of competition among data-using enterprises. But, as long as competition is not completely absent--and there is no indication that this is the case in maritime shipping--the United States should receive some benefits as a consumer of the products and services involved. How much these benefits would amount to is impossible to estimate. As will be shown below, the United States would also profit from expanded production facilitated by increases in the productivity of labor and capital.

Second, unrestricted dissemination might lead to gains in U. S. prestige abroad, for unrestricted disclosure expresses a U. S. posture of sharing international benefits which result from American ingenuity and investment. While such prestige gains would probably be small and shortlived, the avoidance of prestige losses generated by restricted dissemination is apt to be more significant. This would be the case especially if this country were to withhold information which could save lives or reduce pollution in the world's oceans.

Third, there are possible gains from unrestricted dissemination, perhaps on a formally reciprocal basis, of valuable information from other countries. Finally, there are the qualitative benefits concerning the saving of lives and the prevention of environmental decay of the oceans.

It is not possible to quantify the various determinants for calculating the comparative merits of restricted or unrestricted disclosure of SEASAT data. Decision, therefore, must be based inevitably on judgment. However, to exercise choice under these conditions of uncertainty would be relatively easy if monopolist gains available to U.S. businesses from restricted dissemination were demonstrably of so large an order that they overshadowed the values referred to in the countervailing considerations. On the other hand, decision would also be relatively easy if monopolist business gains were unlikely to be large, perhaps of a marginal magnitude. It is interesting, therefore, to look at the rough order of economic gains that might emerge in particular lines of production. For this purpose, we will concentrate on improvements in ship routing, and in the use of offshore structures for oil production from offshore operations.

The annual productivity increases from improved ship operations will be no more than two or three per cent of ship operation expenses, since this is about the percentage of transit time saved. The operation of American-owned ships will directly share in this gain even if the dissemination of SEASAT data is not restricted. These enterprises are high-cost relative to most international competitors, and are subsidized by the federal government. It is quite unlikely that a two to three per cent productivity gain exclusive to U.S. ships will appreciably improve their competitive capacity. On the other hand, the United States would share somewhat in global productivity gains resulting from unrestricted dissemination, for the bulk of seaborne shipping from and to American ports is accounted for by foreign ships. Whether or not this sharing of internationally diffused productivity gains would be larger or smaller than any conceivable range of competitive gains resulting from a monopoly of SEASAT information cannot be estimated. But, if there were a competitive net gain, it would most likely be very small and probably insignificant.

In the case of offshore drilling for oil and gas, SEASAT incremental productivity gains are estimated at about 6% for the North Sea operation but only about 1% for U.S. offshore operations as a percent of production costs. However, in this industry, the United States leads in world-wide capacity and enjoys a very strong competitive position. For this reason, benefits to the U.S. resulting from a monopolistically restricted use of SEASAT data can be assumed to be of a small order. On the other hand, the United States would share in any global increase in capital productivity. In view of projected increases in global demand for oil and gas, any decrease in the enormous capital needs of expanding oil and gas production will help to boost output. Moreover, beyond any doubt, the United States has a strong interest in maximum increases of this output, globally as well as at home, and in the increasing geographic diversification of this output. Such results will improve American supply prospects at reasonable prices.

These considerations lead to the conclusion that restricted dissemination of SEASAT data is unlikely to result in large, if any, economic gains to the United States. On the contrary, it seems reasonable to argue that maximum dissemination of the information should be attempted and to thereby achieve full international employment and maximum distribution of total system costs.

SEASAT and its associated satellites will then function, much like the International Ice Patrol, to attempt to minimize the influence of the natural environment on the profitability or cost and safety of all international economic operations. Thus, the International Ice Patrol provides an existing model for international cooperation and support of an operational system designed to provide for the common good of all users. In this manner, the International Ice Patrol could provide a precedent for international cooperation for an operational SEASAT program.

Achievement of this objective will not be simple. For information to be integrated into private competitive operations will require some modification to the structure of ocean based operations. This in turn necessitates that the operations be assured of the quality, reliability, repeatibility, and continuity of the information. Once such information is assumed and the operation is modified, it is generally difficult to revert to former practices if the information should become unavailable. Yet, no commercial operation wishes to maintain redundant operating forms if the information that SEASAT could supply is to produce operating efficiency.

Thus, the major difficulty that will have to be overcome is that of convincing users of the durable utility of the data that will be supplied through the use of SEASAT. For example, in the case study on ice reconnaissance, users of the Ice Patrol estimated that a period of five years of information supply by SEASAT would be required to prove out the operational utility. Such a requirement by the using community could introduce delays into any international financial contribution for SEASAT's operation, a condition that most likely can be alleviated by the use of SEASAT-A (and SEASAT-B) data in planned operational demonstrations.

SEASAT operational planning must seriously address the problem of affecting the implementation of the opportunities offered by SEASAT's technology by maximizing the availability of SEASAT-A distribution to users which in turn can convince them of the benefit they will acquire from a financial contribution to the operational SEASAT.

The diversity of operations that can benefit from SEASAT derived data introduces the problem of variability in the learning requirement, the termination of which establishes the onset, at least, of the full fee assessment. Implementation will thus require an evaluation, by an independent agent, of the time when the service meets the operational requirement of the service.

Assessment must evolve from some measure of the productivity increase realized by an operation, since the productivity anticipated has a wide range of variability. This requires an objective measure of the realized productivity and some procedure for performing the measurement. It can be expected, that in some forms of operations such as oil production, that productivity by a single operation will not be constant as a function of time and that therefore assessment will also not be a constant as a function of time.

Global forecasting of weather and sea conditions will be dependent, to some extent, on nationally collected data inputs. Effectively it could be argued that the U. S. should then pay for the data received or reduce the national assessment by some equivalent value. If this objective is pursued it may prove extremely difficult to measure the utility of a national data contribution.

If national or international economies benefit directly or indirectly from the productivity of SEASAT derived data, how will the productivity improvement be measured, and how will the nations be assessed?

Presumably, if the U.S. considers itself to be acting as an agent for the continued supply of SEASAT information, it will seek to do so only to offset the system costs. If subsequently system improvements are considered which will evidently benefit only certain operations, updated assessments may prove difficult to formulate.

Finally, the clear status of the U.S. as an agent for the totality of users of SEASAT information must be established since presumably, after the learning period, operations will incorporate SEASAT supplied information and discard old methods and procedures of operation. The agent status will be necessary henceforward as an assurance that the U.S. cannot then manipulate the benefits derivable from SEASAT information.

However, it is evident that the procedure by which user assessment is to be made may be much more complicated than for the International Ice Patrol because of the potential diversity of participation in the SEASAT benefits. Thus, SEASAT operational planning must also address the mechanism of national technical, economic, and political motivations relating to the use of SEASAT data.

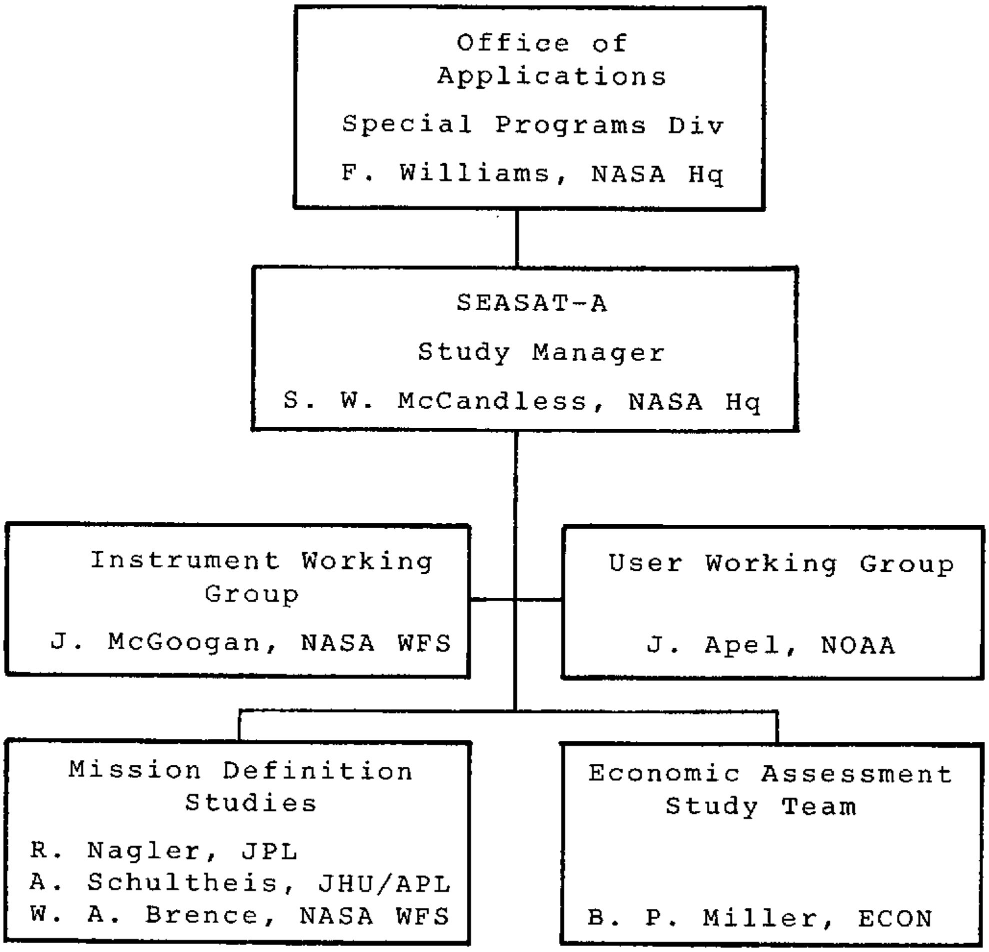
4.0 STUDY METHODOLOGY

4.1 Organization of the Study

The SEASAT Economic Assessment is an integral part of the SEASAT program under the direction of the Division of Special Programs, Office of Applications, NASA Headquarters. The objective of this report is to provide a preliminary quantitative estimate of the benefits which could be obtained with SEASAT-A and follow-on oceanographic satellites including an operational SEASAT system. The Economic Assessment was conducted as part of a multifaceted investigation aimed at defining the mission, technical, operational, and economic characteristics of the proposed program. Figure 4.1 illustrates the organization of the SEASAT program during the period of time covered by this phase of the Economic Assessment. Shown in Figure 4.1 are the key functional elements of the program, along with the individuals responsible for managing the effort in each area.

As shown in Figure 4.1, the key organizational elements of the program are the Users Working Group (UWG), the Instrument Working Group (IWG), the Mission Definition Study Teams, and the Economic Assessment Study Team.

The UWG is responsible for defining an agreed upon set of required measurements and output data compatible with the needs of the individual users of the system, the technical capabilities of the sensors, and the satellite and ground system designs. The requirements established by the UWG are formulated within a framework of realistic program cost, schedule, and milestone requirements. The UWG had an important interface with the Economic Assessment Study Team. At the beginning of the Economic Assessment the UWG assisted in the identification of candidate benefit areas and in the



NASA HQ	=	Natural Aeronautics and Space Administration Headquarters
NASA WFS	=	NASA Wallops Flight Station
JHU/APL	=	Johns Hopkins University, Applied Physics Laboratory
JPL	=	Jet Propulsion Laboratory
ECON	=	ECON, Inc.

Figure 4.1 Organization of SEASAT Program

selection of the case studies to be performed by the Economic Assessment Study Team. As the Economic Assessment progressed, the UWG performed the important function of identifying data sources and verifying the methodology of the case studies. The UWG was chaired by Dr. John R. Apel of the Atlantic Oceanographic and Meterological Laboratories of NOAA.

Instrument system definition was provided by the IWG. In this capacity the IWG obtained measurement requirements from the UWG and provided technical performance, and programmatic data on candidate instruments to the Mission Definition Study Teams. Mr. J. T. McGoogan of NASA Wallops Flight Station was the IWG Chairman.

Two parallel Mission Definition Studies were completed during the time frame of this Economic Assessment. One study was conducted by a team composed from the NASA Wallops Flight Station and the Applied Physics Laboratory of Johns Hopkins University. This team was managed by Mr. W. A. Brence of Wallops Flight Station, and Mr. Andrew C. Schultheis of the Applied Physics Laboratory. A second Mission Definition Study was performed by the Jet Propulsion Laboratory of the California Institute of Technology, and was managed by Mr. Ronald Nagler. The NASA Goddard Space Flight Center supported both study teams in the areas of ground operations and launch vehicle definition. The objective of the Mission Definition Studies was to define the technical, operational, cost, and schedule characteristics of alternative implementations of the SEASAT-A system.

The organization of the Economic Assessment is shown in Figure 4.2 The Economic Assessment Study Team consisted of ECON, Inc. and its subcontractors, Battelle Columbus Laboratories and Ocean Data Systems. The Jet Propulsion Laboratory of the California Institute of California was also a participant in the Economic Assessment Study Team.

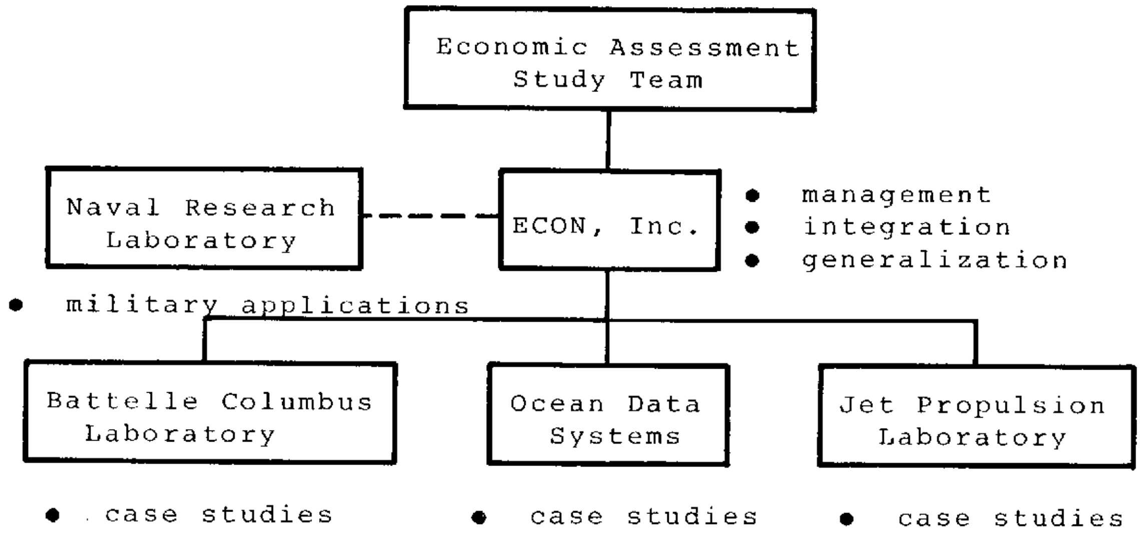


Figure 4.2 Economic Assessment Study Team

ECON, Inc. managed the Economic Assessment, and performed the integration and generalization of the results. The individual case studies were performed by Battelle, Ocean Data Systems, and the Jet Propulsion Laboratory. A parallel economic assessment of military applications was initiated during the later part of this study under the guidance of Dr. Vincent Noble of the Naval Research Laboratory. The military study concentrated on naval applications and provided preliminary inputs for inclusion in this report.

The process of performing the Economic Assessment is shown in Figure 4.3. The case studies were selected to represent areas of maritime operations. Application of SEASAT data to the case studies was expected to improve efficiency in the operations and hence produce benefits. Each case study was an in-depth examination of the parameters of

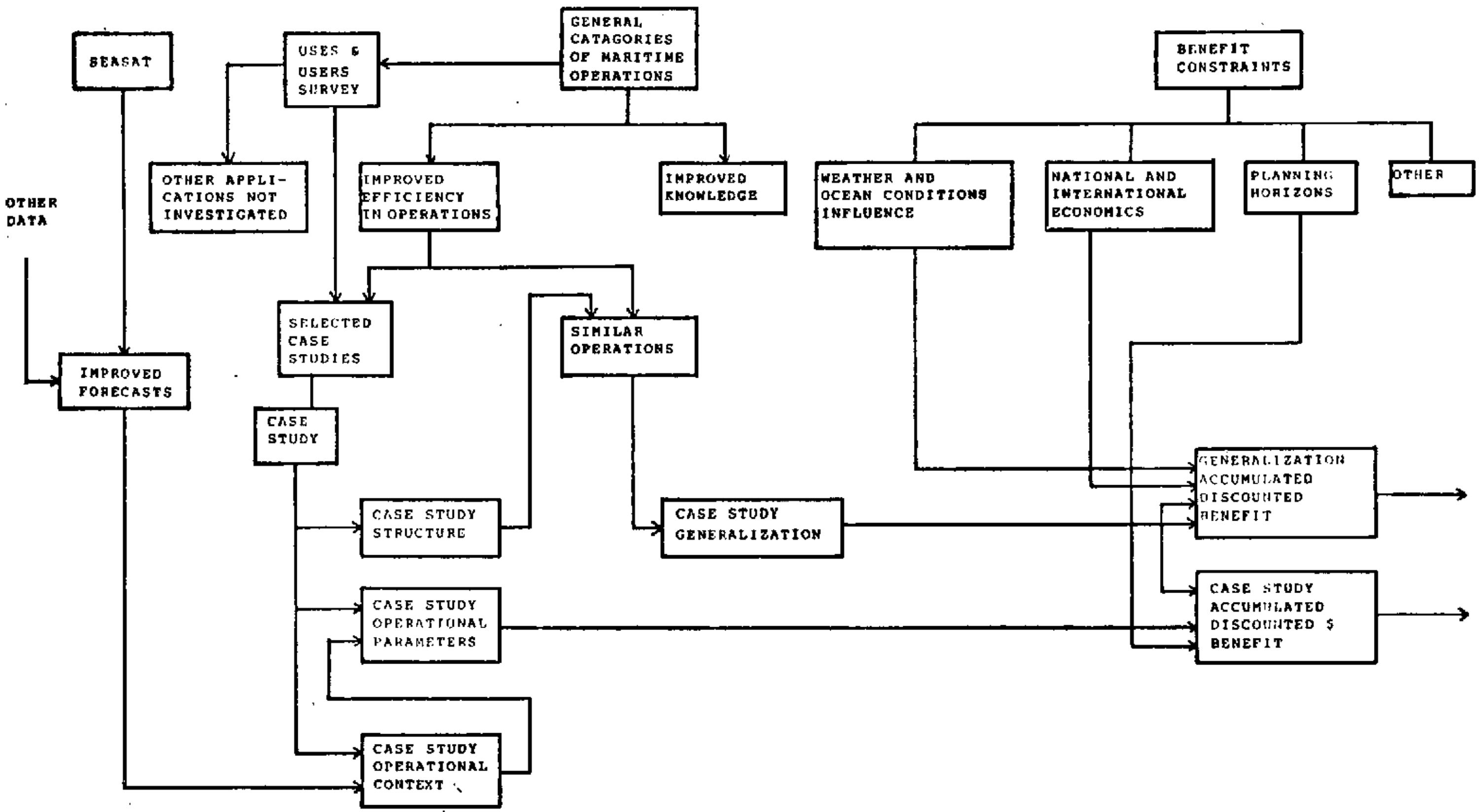


Figure 4.3 Process of Performing the Economic Assessment

operations, technology, and costs, in the selected maritime area. These parameters were evaluated both for current operations, and for current operations with an improved capability for predicting ocean conditions and weather as provided through SEASAT data. The incremental parameter changes attributable to the use of SEASAT data was estimated for each case study and these changes were translated into dollar values.

The process of generalization assumes each selected case study to be one of a set of operations with generally similar technical and operational characteristics. If this assumption was valid, then a generalization was performed, employing where appropriate, econometric modelling to develop the generalized benefits.

Some of the case studies were unique either technically or operationally, and were considered to be complete without generalization.

Figure 4.4 is the schedule and work plan for the Economic Assessment. The effort began during February, 1974 and was completed in June 1974. The case studies were selected from a list of candidate cases that were evolved from a survey of users studies and confirmed in a series of meetings with the UWG in February and March, 1974. The Economic Working Group, consisting of representatives of the organizations conducting the case studies, met monthly during this period to coordinate their efforts. The plans and progress of the Economic Assessment Study Team were coordinated with the UWG and NASA management at the monthly UWG meetings. Draft copies of the case studies were received from the participants in the assessment during late May and early June, 1974, and the integration and generalization of the results were completed during June, 1974.

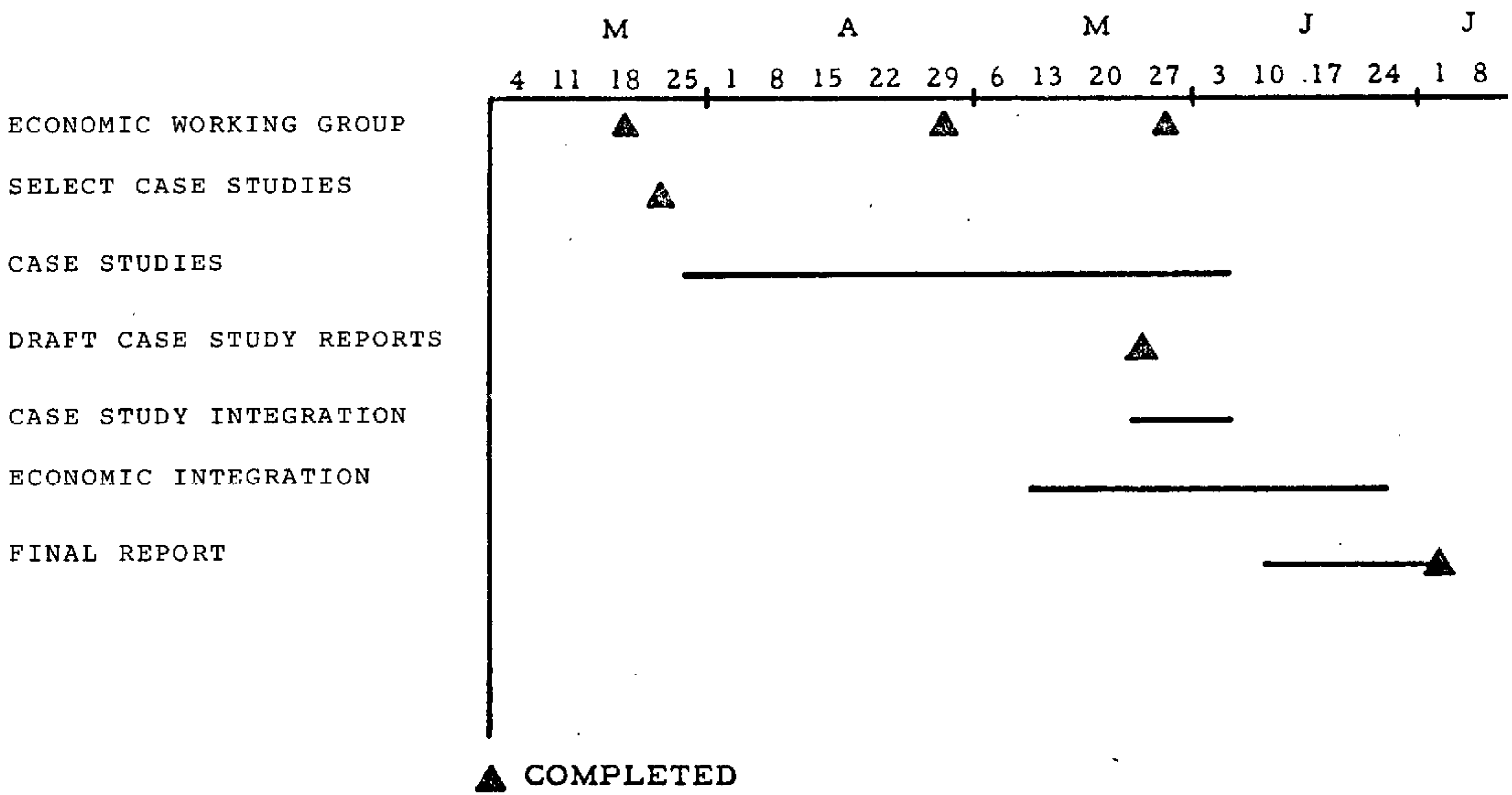


Figure 4.4 Economic Assessment Schedule and Work Plan

4.2 Selection of Case Studies

4.2.1 Introduction

The candidate case studies for this phase of the SEASAT Economic Assessment were selected on the basis of a survey of potential user applications of SEASAT. The survey of the potential SEASAT user community was initiated through the SEASAT User Working Group (UWG) during February 1974. The UWG provided initial suggestions for both uses and users of the SEASAT data. The survey was conducted by performing a review of appropriate literature and subsequently interviewing selected contacts from the prospective user organizations.

The general scope of investigation of SEASAT data uses included both those (a) which could be served by SEASAT-A and (b) which would require an operational SEASAT system. Uses in the former category generally draw on fixed data bases associated with modelling long-term oceanographic phenomena and/or one-time applications such as a worldwide gravity mapping. Uses in the latter category generally require real-time, global, and continuous data to serve diverse operational needs such as for the conduct of offshore oil production and pipelaying operations. It should be noted that Department of Defense applications were specifically excluded in the Survey of users and uses. Applications, important to national security, are being evaluated separately by the appropriate military activities. Clearly, from a technical point of view (required geophysical and ocean conditions parameter measurement attributes) there are important interrelationships between civil and military applications. These interrelationships may either result in compatible instrument/operational requirements and dual benefits or, alternatively, may force a choice between mutually exclusive uses because of conflicting technical requirements.

The survey identified prospective SEASAT users (agencies, institutions, and industries), their intended application of SEASAT data, and the expected area of economic benefit. The results of the survey were then reviewed with NASA management and the UWG. On the basis of their findings, and as a result of this review process, the Economic Assessment Team recommended the implementation of the specific case studies described in this report.

4.2.2 Conduct of the User/Use Survey

Organizations in the private and public sectors which are prospective users of SEASAT provided geophysical and ocean condition data are shown in Table 4.1. Because of the large number of such users and diversity of their interests, it was not possible to carry out comprehensive interviews or to conduct a common correspondence survey. Accordingly, survey contacts were selected and made as follows:

1. Potential uses of SEASAT were screened by technical specialists familiar both in remote sensing technology and in the problem/opportunities of the respective application areas. As a starting list for this exercise, those applications initially identified by NASA and the UWG were used. This list was screened with respect to the following criteria:

   - Collectively, the applications must constitute a fair representation of the leading interests of the prospective user community.

   - Corollary to the above, selected case studies must be sufficiently cogent that the users will be self-motivated to actively participate in the required application analyses.

Table 4.1 Prospective SEASAT Users

- Department of Defense
  - Naval Operations
  - Defense Mapping Agency
  - Fleet Numerical Weather Center
  - Bureau of Ships
  - Bureau of Docks
  - Sea Transport Service
  - Naval Research Labs
  - Naval Oceanographic Office
  - Naval Weapons Labs
  - Environmental Prediction Research Faculty
  - Office of Naval Research
- U. S. Corps of Engineers
- Department of Commerce
  - NOAA
    - National Weather Service
    - National Environmental Satellite Service
    - National Ocean Survey/Geodetic Survey
    - Environmental Research Labs
  - Maritime Administration
- Department of Transportation
  - U. S. Coast Guard
  - St. Lawrence Seaway Commission
- Department of Interior
  - USGS
  - Bureau of Land Management
- Federal Energy Office
  - Office of Oil and Gas
- Atomic Energy Commission
- Environmental Protection Agency

Table 4,1 Prospective SEASAT Users (Continued)

Council on Environmental Quality

State and Local Governmental Agencies

- Regulatory Agencies
- Port Authorities
- Interstate Compacts

Industry

- Geophysical Exploration Companies
- Oil and other Mineral Companies
    - Transport Interests
    - Production Interests
- U. S. Flag Carriers
- A & E Firms
- Shipyards
- Port Operators
- Undersea Cable and Pipeline Organizations
- Fisheries
- Insurance Companies

Research and Technology Organizations

- NSF
- NAS/NAE
- Smithsonian Institute
- Scripps Institute of Oceanography
- Universities and Research Organizations

- With respect to the individual case studies: each one should exhibit a priori promise of benefits. This suggests that we conduct a preliminary analysis prior to commitment, and (b) the case study should be within the time and funding of the Phase I economic assessment study.

2. Based on the findings in the first step, interviews were arranged and conducted with representatives of Federal Agencies having interest in selected application areas. Those areas showing greatest a priori benefit potential are shown in Table 4.2.

   In restricting interviews to Federal agencies, it was assumed that most private interests would be exposed because of private/public sector relationships developed through Federal research and technology infrastructure and regulatory activities.

Table 4.3 lists the organizations and individuals that were interviewed in the user/use study.

4.2.3 User/Use Survey Findings and Conclusions

4.2.3.1 Summary

In overview, the survey findings on promising beneficial applications and their implications for SEASAT instrument/system capability are as follows:

1. Potentially the most promising SEASAT applications drawing on a fixed or historical geophysical base development are (a) determination of gravity anomalies as an aid in oil and mineral exploration, (b) determination of ocean features and dynamics for use in coastal zone management (erosion and subsidence) and in positioning and environmental evaluation of offshore facilities (ports, and drilling platforms), and (c) possibly to a lesser degree, evolution of improved design standards for offshore platforms and for ships.

2. Potentially the most promising SEASAT applications requiring real time or near real time data are (a) geographically local sea state/weather data as an aid in optimizing operations on offshore facilities particularly pipelaying and offshore oil producing facilities, (b) all-weather iceberg

Table 4.2 Prospective Applications and Associated Benefits Derivable from SEASAT Data

Application	Benefit
(1) Protection of Life and Property	
• Navigation and Safety at Sea	• Prediction of High Seas, Adverse Currents • Navigation through Ice Fields • Decreased Loss of Men and Ships
• Warning of Natural Hazards	• Improved Warnings of Storms and Surges • More Accurate, Longer-term Weather Forecasts • Decreased Tsunami False Alarm Rate • More Precise Iceberg Warnings
(2) Economic Benefits to the Nation	
• Maritime Operations	• Optimum Ship Routing and Scheduling • Improved Design of Offshore Structures • Reduced Loss of Oil Drilling Rigs • Improve Utilization of Offshore Rigs • Improve Ship Design • Improved Mapping, Charting, and Geodesy
• Utilization of Ocean Resources	• Assessment of Biological Productivity • Location of Potential Fisheries • Enhanced Extraction of Oil, Sand, Minerals
• Environmental Impact	• Dispersal of Pollutants and Foreign Substances • Improvement in Shoreline Protection • Assessment of Dredging Operations
(3) National Defense Posture	• Improved Environmental Forecasts • More Precise Geoidal Model • Enhancement of Other DOD Missions
(4) Advancement of Knowledge	• Oceanographic and Meteorological Research

Table 4.3 Summary of Organizations Interviewed

National Oceanic and Atmospheric Administration (NOAA)		
Name	Title	Organization
Condr. Dr. John Bossler	Technical Assistant Director National Geodetic Survey	National Ocean Survey (NOS)
Condr. Dr. J. Collins	Deputy Director, National Geodetic Survey	NOS
Dr. H. Schmidt	Director, Geodetic R&D Lab.	NOS
Mr. S. Chovitz	Chief, Physical Geodesy Branch	NOS
Mr. F. Cohen	Office of Coastal Environment	NOS
Dr. G.G. Lill	Deputy Director, National Geodetic Survey	NOS
Dr. M. Orlin	Assistant for Science Activities	NOS
Lt. Condr. C. W. Fisher	Chief, Oceanographic Division	NOS
Mr. S. Hicks	Researcher, Oceanographic Div.	NOS
Capt. L.S. Baker	Director National Geodetic Survey	NOS
Mr. S.R. Haldahl	Leveling Branch/NGS	NOS
Mr. D. G. Carroll	Acting Chief, Gravity and Astronomical Division	NOS
R. Admiral H.D. Nygren	Director	Corps
Dr. H.G. Johnson	Special Studies	Corps

Department of Interior (DOI)		
Name	Title	Organization
Dr. Roland Von Huene	Chief, Marine Geology	U.S. Geological Survey (USGS)
Mrs. Nancy Hart	Marine Geology	USGS
Mr. Clifford Fry	Topographical Division	USGS
Mr. Robert McEwen	Topographical Division	USGS
Mr. Tom Jennings	Environmental Analyst	Bureau of Land Management (BLM)
Mr. Dale Johnson	Chief, Lease Boundaries	BLM
Mr. Clark L. Gumm	Chief, Cadastral Survey	BLM
Mr. Grover Torburt	Coordinator, ERTS, EROS	BLM

Table 4.3 Summary of Organizations Interviewed (Continued)

U.S. Corps of Engineers		
Name	**Title**	**Organization**
Dr. Paul Teleki	Remote Sensing Coordinator Coastal Engineering Research Center	U.S. Corps Engineers/ Coastal Engineering Research Center (CERC)
Dr. J.R. Weggel	Chief, Coastal Engineering Research Center	CERC
Mr. Dennis Berg		CERC
Mr. John Housley	Remote Sensing	Office of Chief of Engineers
United States Coast Guard (USCG)		
Name	**Title**	**Organization**
Comdr. Kennard Palfry	Chief, Oceanography Branch, Ocean Operations Division	USCG/Office of Operations
Mr. R.Q. Robe	International Ice Patrol Division	USCG/Office of Operations
Maritime Administration		
Name	**Title**	**Organization**
Mr. Marion Parr	Assistant Administrator for Maritime Aids	Maritime Aids
Chief John J. Nachtsheim	Assistant Administrator for Operations	Operations
Mr. Marvin Pitkin	Assistant Administrator for Research & Development	Research & Development
Mr. Virgil W. Rinehart	Program Manager Research & Development	Research & Development
American Institute of Merchant Shipping (AIMS)		
Name	**Title**	**Organization**
Mr. Paul M. Hammer	Coordinator of Operations	American Institute of Merchant Shipping
American Petroleum Institute		
Name	**Title**	**Organization**
Mr. B.H. Lord	Director, Division of Transportation	American Petroleum Institute (API)
Mr. A.H. McCoomb		API

location data as a ship navigation aid, and (c) extended (up to 5-day) sea state/ weather forecasts for use in optimum ship routing and scheduling.

3. In virtually all applications, the ultimate realization of potential benefits depends on SEASAT instrument/operating system capabilities which appear to be marginal for SEASAT-A. For example:

   - The ability to calculate gravity anomalies between contiguous points on the order of 0.3 mgal accuracy (required for exploration purposes) from a 1 m geoid or a 10 cm geoid was questioned.

   - Further, a 10 x 10 mile grid size-in contrast to a 1 x 5-mile grid required for oil and mineral exploration appears to be too coarse.

   - Imaging radar resolution of 50 m is insufficient for ice patrol purposes. Ten or 25 m resolution is much preferred. An example of a problem here is that of discriminating between fishing boats and icebergs. In this example, fishing boats may not leave a wake while icebergs might. The imaging radar, through measurement of ocean features pertinent to ice patrol would be useful in decisions on follow-up aircraft surveillance.

   - 100-km resolution for the microwave radiometer is not sufficiently precise for determination of the commingling of Labrador and Gulf currents and for decay rate (and, hence, location/ movement of icebergs.)

Given continued evolution of SEASAT instrument, system and data dissemination capability, Federal "user agencies" expressed interests in 15 application areas. These are listed in Table 4.4 under four general headings:

Table 4.4 Principal Applications of SEASAT Data Considered In the User/Use Survey

(1) Applications of the Geoid	• Unified geodetic datum and coordinate system • Deflection of the vertical component for inertial navigation • Leveling measurement for monitoring land subsidence • Gravity anomalies for use in oil and other mineral exploration • Refinement of the gravity field for upgrading accuracy of geopotential models • Measurement of mean sea level slope important to oceanographic studies • Ocean dynamics attributable to barometric pressure, storm surges, tsunamis, ocean currents, wave lengths, and tides
(2) Off-Shore Facility Applications	• Sea-state monitoring and prediction for improved operations in pipe laying and rig operations • Ocean dynamics historical information for improved design criteria for rigs, deepwater maritime terminals, power plants, and ships • Geographic specific ocean dynamic information for off-shore facility siting
(3) Ice Reconnaissance	• Iceberg location and movement to aid navigation on North Atlantic trade routes • Great Lakes monitoring of ice leads, ice ridges, thickness, etc. to facilitate a longer open season and improved operations • Measurement of ice ridges, floating ice, etc. to facilitate design and operating procedures in Artic rig operations
(4) Ship Routing/Navigation	• 5 - 7 day sea-state/weather forecasts to facilitate maritime logistic system planning and scheduling • Real time sea-state/weather information to optimize navigation and enhance safety at sea

Applications of the Geoid, Offshore Facility Applications, Ice Reconnaissance, and Ship Routing/Navigation.

4.2.3.2 Application Interests of Selected Agencies

4.2.3.2.1 National Oceanic and Atmospheric Administration (NOAA)

Application areas in which NOAA representatives expressed principal interest are coastal zone subsidence, gravimetric and other surveys, sea level monitoring, and current circulation (Table 4.5).

An important application of SEASAT (provided a 10 cm geoid can be accomplished) is in tying the various tidal stations to one reference datum for adjustment of leveling networks on a worldwide basis. Although useful in strengthening the leveling network, NOAA could not ascribe an a priori monetary value to its benefit. Users who would benefit most are coastal engineers who are interested in determining mean high water for dock sites, thus leveling from a tide station to the site. Interest focuses particularly on the rate of movement of coastal areas for determining structures that can last say 100 years. In areas of land subsidence, such as in Long Beach, California (27 ft in 20 years), and in Houston, Texas (1.2 ft.year) losses incurred by properties, and structures could be very costly. A land example further illustrating the practical significance of improved leveling concerns a tunnel construction project in Switzerland. In this case leveling was done simultaneously starting from the Mediteranean side across the Alps and another network from the German side. The difference at the tunnel midpoint was 80 cm in elevation which was resolved at considerable cost.

Table 4.5 Summary of Application Interests and Associated System Requirements: National Oceanic and Atmospheric Administration

Coastal Zone Subsidence	Tying tidal stations to a one reference datum for worldwide adjustment of leveling networks.
Gravimetric and Other Surveys	Refinement of the geoid measurement to improve knowledge of the gravity field, reference coordinate system, and positioning navigation accuracy.
Sea Level Monitoring	Effects of land movement and glacier melting on mean sea level fluctuation.
Coastal Current Circulation	Improved knowledge of wind driven circulation and its effect on current behavior.

Determination of a 1-m (or 10-cm) geoid will greatly facilitate gravity and other surveys. A 1-m geoid is important to improving knowledge of the gravity field, the coordinate system or reference datum and the positioning/ navigation accuracy required in gravimetric and other surveys. In particular it should improve determination of lease boundaries and oil platforms more accurately. At present, a region of about 1/4 of a mile from lease boundary lines are left undeveloped. Further, tying land surveys and control systems with surveys at sea should be of additional national benefit. It is estimated that the present accuracy of the equatorial radius is about 5 meters with about 2-3 meters in each of X, Y, and Z. Conversion between rectangular and cylindrical coordinates is essential.

4.2.3.2.2 Department of the Interior (DOI)

Application areas in which DOI representatives expressed principal interest include gravity mapping, water resource monitoring, environmental control, and ice reconnaissance (Table 4.6).

DOI representatives indicated that a highly accurate gravity mapping capability would have definite benefits, but would be hard to obtain because current surveys collect a large variety of information in addition to gravity data. The knowledge of the location of gravity anomalies would indicate those areas most likely to be of interest for detailed surveys. Benefits could be computed on the basis of surveys not made by conventional methods; i.e., surface reconnaissance surveying could possibly be eliminated in favor of SEASAT source data. Estimates for current methods of data collection by ship surveys are:

1. Ship and ships crew costs are $2000 per day and travels at approximately 6 knots while taking seismic, magnetic, gravimetric, bathymetric and other data at a rate of 200 miles/day.
2. A gravity meter costs $500,000 and will last 10-15 years with a $300,000 per year expenditure for maintenance and update of capabilities.
3. Data reduction costs approximately $75 per day this includes only the transfer of information from the log tapes.
4. The salaries for the scientific crew are $60,000 for six months or $120,000 per year. A typical scientific crew consists of six people, two per shift, three shifts. One person covers gravity meter, the other seismic and magnetic data collection. Some processing is done on-board.
5. The ships cover a 20-mile grid on the continental shelf.

Table 4.6 Summary of Application Interests and Associated System Requirements: Department of Interior

Gravity Mapping	Global gravity mapping for scientific purposes and local determination of gravity anomalies for resource exploration.
Water Resource Monitoring	Freshwater absorption in oceans and estuarial.
Environmental Control	Consideration of environmental impacts in off-shore leasing decisions.
Ice Reconnaissance	Effects of ice coverage and movement particularly in Northern latitude coastal zones.

These costs convert to about \$12-\$15 per line mile for the gravity part of the survey exclusive of equipment amortization.

In this application area DOI has extensive gravity data that were taken over the South California borderland with known oil production and reserves. This area could make a good scientific case study, because of the availability of good correlation of the gravity anomaly with the bottom structure. DOI has constructed a free air gravity map of 10 mgal contour interval with an estimated accuracy of their gravity anomalies to be better than $\pm$ 2 mgal. DOI is primarily concerned with the offshore areas up to the continental rise. They have operated in the Bering Sea, the Gulf of Alaska, Gulf of Mexico, and special deep water areas. Although their gravity surveys are integral parts of their ship seismic, magnetic and other geophysical measurements as indicated above, it is possible to isolate the costs associated with the gravity operations (salaries, instrument, data reduction, and other costs). They stated that to use gravity for local resource development, accuracy of the order of 0.3 mgal will be required. There will be a problem with gravity anomalies, derived from SEASAT, resulting from distant mass concentrations.

In the area of water resources, DOI has collected considerable amounts of data in the San Francisco Bay area; an example of a need for SEASAT although it is eight years too late. Of particular interest is the study of how fresh water is being absorbed into oceans and estuaries.

The Environmental and Marine Minerals Division of the Bureau of Land Management (BLM) prepares environmental statements for oil, gas, and sulphur extraction operations on the outer continental shelf. They are now writing regulations to permit dredging leases. The Corps of Engineers has the dredging responsibility on the continental shelf. The BLM is trying to get authority to control dredging for the outer continental shelf. Under current laws and agreements they are directly involved in oil rig design and operations as well as offshore common carrier pipelines. In essence, they are charged with the consideration of environmental concerns in leasing decisions.

The application of SEASAT data here would be as a secondary historical data base. The benefit foreseen from SEASAT would be in the reduction of the time necessary to collect environmental information to make the leasing decision. Currently, approximately two years are needed to collect sufficient information with enough statistical reliability to use in their environmental reports.

4.2.3.2.3 U. S. Corps of Engineers

Application areas in which the Corps expressed principal interest generally lie in the domain of coastal zone management. Specifically, Corps interest centers on offshore structures, offshore dredging, shore and river mouth ice monitoring, beach erosion, pollutant dispersion, and storm forecasting (Table 4.7). The Corps expressed little interest in deep ocean applications except to indicate that improved synoptic weather/sea state knowledge would serve their concerns in coastal storm surges and hurricanes.

With respect to offshore structures, the Corps (along with DOI, MARAD, USCG, and EPA) is becoming increasingly involved. In particular, they are in the continuing process of evolving design standards for deep-water ports and for single point mooring systems. Their primary need in this instance is for historical synoptic data for continental shelves,

Table 4.7 Summary of Application Interests and Associated System Requirements: U. S. Corps of Engineers

Off-Shore Structures	Design criteria - specifically for ports and single point mooring systems.
Ice Monitoring	Ice-shoreline interface ice build-up at river mouths.
Storm Forecasting	Coastal area wave/weather effects.
Beach Response	Erosion and land subsidence investigations and control
Off-Shore Dredging	Sedimentation buildup and movement.
Waste Disposal and Pollution	Current patterns effects on pollutant dispersal

of wave heights, length, and direction, ocean currents speed and direction (surface and bottom currents) and surface wind forces.

Beach erosion studies are a subject of major interest to the Corps. However, it is doubtful that SEASAT instrumentation would yield the degree of data resolution needed for this purpose. Specifically, a 5 to 20-foot horizontal resolution and a 1-foot vertical resolution was cited as minimum requirements for beach erosion studies. Actually desired resolutions are 1 foot horizontally and 6 inches vertically.

At present the Corps relies on on-site mapping by field crews, stating that it is more accurate and cost-effective than aerial photo reduction. Notably, in the SEASAT time frame, advanced techniques for enhancing photo imaging may change this situation; and along with growth curve improvements in SEASAT instrumentation, make satellite shoreline mapping practical.

Overall, current activities of the Corps to which SEASAT might eventually be applied (Table 4.7) required instrument upgrading. For example, for effective coastal zone work, the currently proposed $\pm$ 20° wave direction capability should be reduced to $\pm$ 10° generally and to $\pm$ 3° for some geographic preference areas. The resolution of the imaging radar should be 25-m (consistent with USCG requirements for ice reconnaissance), and altimeter resolution (at the ocean/shore interface) should yield the horizontal and vertical resolutions cited above.

4.2.3.2.4 The Maritime Administration (MARAD)

The Maritime Administration has one overriding objective: to improve the capability and cost-effectiveness of U.S. merchant shipping relative to that of non-U.S. flag carriers. Inferred ramifications of this objective are to expand the U.S. flag share of oceanborne commerce and to reduce federal operating and ship construction subsidies (as prescribed in the Merchant Marine Act of 1970). Exploitation of advanced technology for the exclusive use of U.S. flag carriers is viewed as the most promising mechanism for achieving these ends. It is this technology orientation which underlies MARAD interest in potential applications of SEASAT.

Within the above-stated context, MARAD officials expressed interests in applications associated with ship routing/navigation, safety at sea, ship design, and offshore structures (deepwater terminals). These areas of interest are summarized in Table 4.8. Their expressed interest in the use of satellite technology for these purposes is mainly for improved communications, secondarily for improved real-time weather information, and finally for better sea state information.* The potential applications of SEASAT in this connection are twofold. First, sea state data along with other weather satellite data (and associated command and control) would yield benefits in ship routing and navigation. Second, historical global and geographic specific sea state data would facilitate siting and design of offshore terminals and design of ships.

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* In a 1973 study, "Remote Radar Transmission, Processing and Display", prepared by AII Systems for the U.S. Maritime Administration, it was estimated that an Integrated Communications, Collision Avoidance and Navigation System (ICCANS) based on satellite technology application would yield net benefits of $3800 to $47,800 per ship per year, assuming 515 using vessels. These benefits would accrue from (a) substitution for present communication equipment, (b) reduction of on-board function, (c) increased ship productivity, and (d) reduction in casualty losses. Ship productivity, of which improved weather routing is a major contributor, accounted for the majority of the benefits; ranging as high as 70 percent of total benefits in some instances.

Table 4.8 Summary of Application Interests and Associated System Requirements: Maritime Administration	
Ship Routing/Navigation	Real-time communication and control of ship operations at sea.
Safety at Sea	Storm avoidance and corrective action (e.g., maneuverability).
Ship Design	Advanced technology in ship design and construction methods.
Off-Shore Structures	Siting, design, and operations of deepwater terminals.
Ice Reconnaissance	

Potential applications of SEASAT by MARAD and its end-user constituents (U.S. flag carriers and shipyards) are promising in two respects: (a) the MARAD program organization and associated commitment to improve maritime operations through the use of satellite technology provides an available and on-going mechanism for the conversion and dissemination of satellite source data to end-use specifications, and (b) economic benefits derived from such applications can yield a directly measurable effect on Federal expenditures for ship construction and operating subsidies. A possibly limiting factor in such applications, however, is that MARAD is dedicated to promulgating benefits exclusively for U.S. industry as noted at the outset of this section.

4.2.4 Applications Case Studies Selection

Based on the SEASAT application opportunities discussed in the foregoing, and in cooperation with NASA Management and the UWG, the following case studies were selected:

1. Civil Application of the Geoid
   - Offshore oil exploration (primary)
   - Leveling with application to land subsidence (secondary)
   - Oceanographic applications (secondary, with focus of scientific value).
2. Offshore Structures with Case Study Focus on North Sea Oil Recovery Operations
   - Pipelaying operations
   - Rig construction and operation
3. Ice Reconnaissance
   - Navigation through the Grand Banks iceberg region (USCG International Ice Patrol program)
   - Great Lakes ice monitoring
4. Weather Routing and Port Operations Associated with the Valdez, Alaska - West Coast Tanker Operations
5. Optimum ship routing for Trans-Pacific Merchant Vessel Operations (primary) and Selected Tanker Operations (secondary).
6. Port, Harbor, and Dockside Operations

In addition to the above, it was assumed that the primary military interest would be as a result of information derived from knowledge of the geoid. These case studies and their relation to selected national interests are shown in Table 4.9.

Table 4.9 SEASAT Case Study Options and Their Association with National Purposes

National Purpose / Application Study	Natural Resource Exploitation	Energy Supply Independence	Navigation and Safety at Sea	Marine Facility Equip. Design/ Operations	Environmental Monitoring/ Protection	Natural Hazard Warning System	National Defense	Education and Knowledge
Civilian Application of Geoid								
Petroleum and Mineral Exploration	●	●					●	
Quasi-Stationary Determination of Geoid	●	●			●	●	●	●
Horizontal/Vertical Geodetic Controls	●	●	●	●		●	●	●
Geophysical Model Input	●	●	●	●	●	●	●	●
Off-Shore Structures								
Oil/Gas Drilling Rigs	●	●		●	●			
Pipeline Laying	●	●		●	●			
Ice Reconnaissance								
North Atlantic			●	●		●		
Great Lakes			●	●		●		
Alaskan Tanker Route Operations	●	●	●					
Optimum Ship Rotuing in the North Atlantic			●					
Port, Harbor and Dockside Operations				●	●	●		
Military Application of the Geoid							●	

In addition to the potentially broad contributions to selected national purposes (as indicated in Table 4.9), the following complementary linkages among the case studies are noteworthy:

- Three case studies are associated with oil, gas (or mineral) exploitation. These are civil application of the geoid (exploration), offshore rig operation (oil or gas recovery), and offshore pipelaying (oil transport). This, apart from design standards, a relatively complete profile of applications of SEASAT in offshore oil exploration will be covered.

- Three case studies are associated with ship routing and navigation. These are iceberg reconnaissance in the Grand Banks region, trans-Pacific weather routing of merchant vessels, and Alaskan-West Coast tanker operations. Thus, SEASAT implications for routing and navigation will be treated with respect to open sea and coastal shipping, tanker and general cargo vessels, and weather and natural hazard conditions.

- Potential benefits of improved ocean condition forecasts will be treated in three case studies. Two studies (Alaska-West Coast tanker operations and trans-Pacific ship routing) are concerned with "global" (trade route) forecasts. Also, two studies (North Sea offshore operations and port, harbor, and dockside operations) are concerned with geographic specific forecasts.

- Geoid applications case studies encompass direct economic concerns (oil exploration and land subsidence), national security interests (inertial navigation), and scientific interests (oceanography).

Tables 4.10, 4.11, and 4.12 summarize the correspondence between the planned SEASAT instrument package, geophysical parameters to be measured and the use and user applications for the selected case studies identified above. Table 4.10 contains the same information as that described in the NASA internal document, "(SEASAT) Operational Ocean Information Capabilities in 1982". Table 4.11 shows the primary and secondary geophysical parameters associated with the respective case study applications. Thus, for example, applications of the geoid draw primarily on measurement of geoidal heights, and secondarily on corrections for tides, wave spectra, etc. Table 4.12 identifies those organizations which would have leading interest, either as intermediate or end-users, in the respective case studies and their extended generalizations. Thus, for example, the petroleum industry would have immediate interest in the utility of 48+ hour reliable weather/sea state forecasts for North Sea rig and pipelaying operations. Extension of this application for similar operations in other geographic areas and for dissimilar, but geographic specific, offshore facilities would lean toward broadened interest including organizations such as MARAD, port authorities, AEC, USCG, and U. S. Corps of Engineers.

Table 4.10 Relationships Between SEASAT-A Instruments and Geophysical Parameters

	Radar Back-scatter (Scatt-erometer)	Microwave Em-ission (MW Radiometer)	Altitude & Roughness (Ra-dar Altimeter)	Radar Images (Imaging Radar)	Infrared Im-ages (IR Ra-diometer)	Ocean Geoid (External Data)	Satellite Position (Ex-ternal Data)	Other Obser-vations (Ex-ternal Data)	
Atmospheric Water Content		•			•		•	•	
Surface Winds Speed & Direction	•	•	•	•			•	•	
Wave Heights, Length, Direction	•	•	•	•			•	•	
Wave Near Shore & Storms			•	•			•	•	
Geoidal Heights			•			•	•	•	
Surface Currents Speed & Direction		•	•	•	•	•	•	•	
Tides, Tsunamis Set - Up Storm Surges			•			•	•	•	
Sea Surface Temperatures		•			•		•	•	
Ocean, Ice, Atmos-phere, Land Features	•	•	•		•	•	•	•	

Table 4.11 Correspondence Between Geophysical Parameters and Selected SEASAT Applications

	Applications of Geoid (Civil/Military)	North Sea Rig Operations and Pipelaying	Ice Reconnaissance	Alaskan Tanker Operations	Pacific Trade Route Weather Routing	Port, Harbor and Dockside Operations
(1)	•					
(2)		•	•	•	•	•
(3)	•	•		•	•	•
(4)		•		•		•
(5)	•					
(6)		•	•			
(7)	•	•		•	•	•
(8)	•		•			
(9)	•	•	•	•	•	•

Table 4.12 Principal Users of Selected SEASAT Applications and Their Extensions

	Applications of Geoid	Offshore Rig Operations and Pipelaying	Ice Reconnaissance	Alaskan Tanker Operations	Pacific Trade Route Weather Routing	Port, Harbor and Dockside Operations
DOD	•				•	•
U. S. Corps of Engineers		•	•			•
NOAA	•					
MARAD		•	•	•	•	•
USCG			•	•		
DOI	•	•	•			
FEO	•	•				
AEC		•				
EPA		•		•		•
Port Authorities		•	•			•
Petroleum and Mineral Industry	•	•	•	•		•
Maritime Carriers		•	•	•	•	•
Construction Industry	•	•				
Insurance Industry		•	•		•	•

4.3 Analysis of Benefits

SEASAT's instrumentation will provide globally structured data about sea conditions which were not previously available. Appropriate processing of this data and its subsequent integration with data from many other diverse sources will provide new predictive information about the sea-atmosphere interface, ocean topography, and weather. It is assumed that data processing will produce new information of quality appropriate to each of a number of maritime operations with different characteristics.

This new predictive information provides an opportunity for many national and international operations, generally of a maritime nature, to improve their operating efficiency, and to develop benefits from the new information. This process of benefit development is illustrated in Figure 4.5.

If each maritime operation is viewed as a system, then it is structured as an interconnected set of functional activities taking place mostly in the context of the sea and therefore influenced in its operating efficiency by uncertainty about sea conditions. Generally, operating experience forms the maritime operation into a quasi-optimal operation within an observed assessment of operating constraints, such as those imposed by lack of predictive knowledge of the sea conditions. In effect, each operation is penalized in its operating efficiency by the operating constraints.

The new predictive information to which SEASAT contributes may interact or influence some or all of the functional activities which make up the maritime operation. Through these interactions, the efficiency of the maritime operation can be improved.

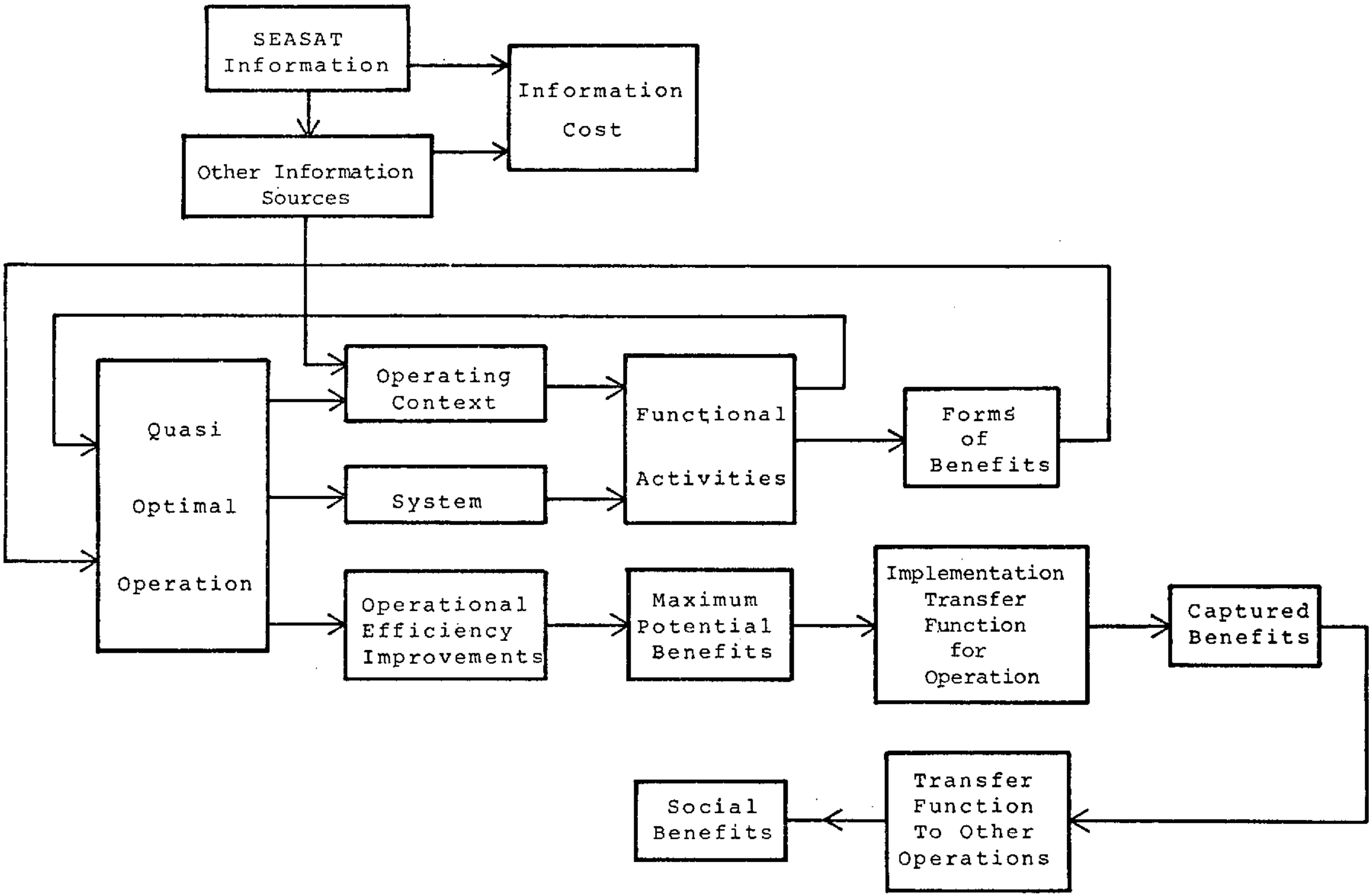

Figure 4.5 Process of Benefit Development From New Information

This improvement is usually identified in terms of a parameter or parameters describing the functional activity. That is, parameters are modified by measurable effects from which improved efficiency can be deduced or computed and directly related to some aspect of the new predictive information made available. Thus, the improved efficiency will persist providing that the new predictive information and the functional activity persist. This implies that the technology of the operation as a functional activity remains fixed or does not change to reduce the influence of the new predictive information. These persistencies give rise to a planning horizon or time period during which the estimated efficiency continues and, hence, a time interval over which the efficiency improvement can be aggregated in some appropriate form.

An improvement in efficiency as created from the interaction between a functional activity and new information can generally be implemented within the operation in two fundamental ways. That is, the functional activity may stay unchanged, but the resources needed for its accomplishment may decrease, a form of equal capability or performance efficiency. Or, the resources may remain constant, but the functional activity may become more productive, a form of equal resources efficiency. In a general functional activity, combinations of these forms are likely to be appropriate in the sense that the functional activity should be able to absorb a combination of the two forms of efficiency without consuming resources in the process, to essentially maximize the incremental movement toward optimality in the operation.

When the functional activity can absorb some combination of the two forms of efficiency without consuming resources in the process, the efficiency can be described as effective efficiency. Effective efficiency or its degree of achievement depends on the structure of the functional activity and the response of that structure to the new information.

It is customary to measure efficiency improvements in terms of dollars of a constant value and to discount efficiency improvements in the future from the time when they will occur back to some fixed time. When this is done over a planning horizon, then a normalized gross benefit is assigned to the operation as a consequence of the new information. Measuring efficiency improvements in constant dollars allows normalization to be performed as a capital discounting process to produce a present value of future efficiency. The choice of the discount rate selected must result either from edict, be carefully chosen, or be illustrated by parametric choice of alternative values. Generally, to obtain and sustain the new information requires an expenditure of resources so that a normalized expenditure can be determined for the cost of the information as for the benefits. The difference between the normalized gross benefit and the associated normalized expenditures are incurred before gross benefits materialize. Hence, for a positive net benefit, benefits must grow at a rate considerable in excess of the growth of expenditures. The net benefits developed generally reside in the operation being studied.

The discussion of benefits so far is essentially a theoretical one in which the consequences of the availability of the new information are evolved carefully within an assumed operating framework for the functional activities that are influenced by the new information. That is, the theory can allow the new information to be completely integrated into the functional activity and, thereby, into the operation. In this sense, therefore, the benefits have the character of maximum potential benefits.

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In practice, however, this maximum may never be achieved because its implementation may not be (or may not seem to be) effective in terms of the operatives of the operation. The theory tends to assume everything is possible, whereas, in practice, there may be many forms of non-technical or non-technological constraints on implementation or integration. When the practical aspects of implementation are fully investigated to determine what is effective or reasonable, then it is possible to consider benefits that are captured within the operation. Generally, these <u>captured benefits</u> will be less than the maximum potential benefits. The captured benefits are captured by the operation and reside within it. That is, it is a choice of the operatives of the operation to decide how the benefit will be treated. In a general sense, this is true whether the operation is public or private. The operatives may elect to allow some of the captured benefit to pass out from the operation itself and thus become a benefit to a larger social group than the operatives themselves. As such, an 'escaped' benefit propagating to interact with larger social groups at some stage becomes a social benefit. In the propagation process, many operations are involved, within each of which the operatives may elect to retain or to allow benefits to 'escape'. Thus, it is that social benefit, in practice, is extremely difficult to define and to measure quantitatively. Insofar that operations are economically interdependent entities, economics can, on the basis of its theory, define what should occur within an operation to sustain some basic economic parameters and, thus, trace out a social benefit based on an economic theory of the reasonable.

In this economic assessment, potential and captured benefits are discussed and estimated. Social benefits are not. Subsequent sections discuss benefits as they are treated in this study.

4.3.1 Forms of Benefits

The application of SEASAT information is assumed to produce improvements in the efficiency of maritime operations. The maritime operations most likely to benefit from SEASAT information are:

1. maritime transportation;
2. maritime exploration, exploitation, and extraction of sub-sea natural resources.

For these operations, unforeseen or unavoidable transitions to some sea surface state or conditions modify or cause transitions in operating characteristics. If the operations are viewed as coherent and quasi-optimized technical and economic processes, these transactions in the operating environment cause departure from the optimization. Essentially, the sea surface state is part of the context of these operations and, to the extent that its prediction is not complete, makes operation optimization difficult. Operations, most generally, must be planned to be effective in responding to worst case expectation in many factors, employing the resources of the operation just to accommodate these worst case expectations.

Benefits from SEASAT to the operation derive, therefore, from the release of all or some part of the resources required to accommodate these worst case expectations of the operation planning.

4.3.1.1 Maritime Transportation Operations

The operation of maritime transportation is a technical and economic process from port of origin to port of termination. Planning incorporates the dockside operations of loading and unloading, the actual open sea transit and all activities associated with the ship, the crew, the cargo, and the freighting contract.

Sea surface state prediction can have an evident influence on the voyage transit time insofar as it can permit the selection of a route which will maximally allow the ship to be operated at its most economical speed, thus minimizing the cost of transit. Prediction time must then be related to the regional size of adverse sea-state conditions and the vessels' most economical operating speed, but not as a simple tradeoff, to find the optimum route.

If an optimum route can always be followed given a synoptic sea-state prediction, then the transit time will always be optimized and the transit integrated operating cost will be minimized.

A consequence of minimized transit time is that a repetitive freighting task can be undertaken by a smaller number of ships requiring less capital investment in ships. Or with the same number of ships, but of smaller displacement, both less capital investment is required and repercussions on port construction cost and channel and straits utilization on the routes can be anticipated. However, not all of this gain can necessarily be realized because preventive maintenance and overhaul costs may increase because of the increased utilization.

Optimum routing implies the avoidance of weather or ocean conditions that will require a reduction in operating speed. It, therefore, also implies a transit that will minimize the stresses to which the ship will be subjected, thereby prolonging its operating life. Alternatively, this could perhaps permit ship design with reduced safety factors and thus result in a less costly ship. A further possibility is a transit in which the risk hazard is reduced, giving rise to an opportunity for a reduction in insurance premiums. This latter advantage can arise either from a willingness on the part of the owner to self-insure a larger fraction, or from an effective rate reduction granted by the marine underwriters.

If freighting contracts are written with delivery time variance penalties, then reduction in transit time variance can minimize the expectation of payment of such penalties provided that the contract form remains the same.

When transit time reduction can result from improved routing, the full consequences of the derived benefit require that loading and unloading, i.e., the terminal port operation, be structured to take advantage of the reduced transit time. This implies an integrated management concept for the operation.

Maritime transportation benefits from SEASAT information can have the following origins:

1. Ocean transit time minimization
2. Optimization of the structure of a freighting fleet
    a. less ships
    b. same number of ships with reduced displacement

3. Ship stress minimization or ship design with reduced safety factors
4. Ship life extension from reduced damage due to weather
5. More cargo shipped
6. Marine insurance premium reduction
7. Reduction in freighting contract penalties.

Case studies that investigate benefits dealing with maritime transportation were selected as follows:

1. Iceberg reconnaissance, monitoring, and prediction in the vicinity of the Grand Banks, Newfoundland, and eastwards
2. Crude oil transportation from Valdez, Alaska, to U.S. West Coast ports
3. Containerized and other freight shipping eastwards and westwards between the Far East and U.S. West Coast ports
4. The influence of SEASAT information on dockside operations.

4.3.1.2 Operations for Maritime Exploration, Exploitation, and Extraction of Sub-Sea Natural Resources

These operations are concerned with the locating of sub-sea natural resources and with the installation and operation of sea located structures and their ancillary equipment for the exploration and extraction of the sub-sea resources.

Possible sites of natural resources are located with increasing precision by a sequence of investigations which identify mass anomalies, magnetic anomalies, and seismic anomalies before sample drillings are undertaken. Mass anomalies are essentially characterized within the structure of the geoid which must be determined for the development of ocean condition data. If, from the determined structure of the geoid, localized area anomalies can be adequately located, the geoid information can be used to expedite the initial phase of potential natural resource location. This reduction in time would be a benefit.

Once a promising sub-sea natural resource (crude oil, gas, minerals, etc.) pool has been defined, exploration requires sample drillings. Extraction requires additional drilling and the installation of pipe lines to extract the flow if oil or natural gas is the resource.

These operations require the location of sea-based structures anchored or located on the sea floor and some associated platform and rig structures. Additionally, pipe laying requires the employment of specialized barges.

Operations are dependent on the existence of reasonable sea-state conditions over a time interval, say of 48 hours, so that crews can be shipped to the operations site and then perform operations over a reasonable time interval using equipment which is also transported to the site. Weather and ocean conditions can then cause non-productive expenditures for labor and equipment. Reducing these non-productive expenditures produces a potential benefit.

If the design of the sea-based platforms, rigs, and other structures was a very refined science, accurate predictions defining the characteristic environmental conditions could be employed to carefully refine the design and minimize the structural design costs. However, structural design procedures are at present based on an expected (but uncertain) worst case environment, and include a factor of safety to account for this uncertainty. Considerable energy is being directed to further understanding of design requirements because of the great increase in use of rigs and platforms for oil exploration and accurate global environmental data may be an important factor in the future.

If rig and platform design were more carefully matched to the operating environment, then, presumably, damage to or loss of the structure would be less likely and rig and platform insurance premiums could be reduced.

Benefits will be sought from SEASAT information from the following sources:

1. Improvement in geoid knowledge and its employment for improved location of gravitational anomalies related to oil exploration
2. The impact of sea-state predictive 'windows' on the exploration and extraction of sub-sea natural resources.

Case studies that investigate benefits dealing with maritime exploration and exploration and extraction of sub-sea natural resources were selected as follows:

1. Geoid knowledge improvement and its relevence to natural resource location
2. Sea-state prediction influence on the exploration and extraction of sub-sea natural resources in the North Sea.

4.3.2 Captured Benefits

The forms of benefits discussed in the previous section result from logically tracing the operational consequences of information supplied by SEASAT technology within the framework of the operations.

Correctly performed, therefore, the benefit analysis produces a maximum potential benefit by assuming a logical integration into the operations of all the improvements that the technology will provide.

Practically, this implementation may or may not occur, particularly when the integration requires consensus and expenditures for a common result among and by organizations under different control. That is, the organizations involved may not have common goals unless cooperation is actively sought.

Even when benefits are possible within the operations under the control of a single organization, the benefits will only be captured if the organization enacts procedures to permit the capture. These procedures will be implemented only if the benefits possible appear to be desirable to the organization. This generally implies that procedure changing expenditures within the organization and continued confidence in the potential benefits are compatible and controllable by the organization. Under these conditions the organization will seek to take advantage of the opportunity made available by the new information.

Captured benefits relate, therefore, to effective efficiency improvements within organizations, and what is effective can only be studied within the economic framework of the existing organizational structure and procedures.

When operations are commercial, and, therefore, generally competitive, operational organizational procedures are often closely guarded to sustain competitive positions. Operations that are conducted under public or governmental aegis do not reflect commercial competitive constraint, but sometimes their operational forms are diffuse and difficult to interpret.

Benefits of concern to the SEASAT program are benefits that are captured or realized. Precise determination of the captured benefit value is, however, in general, extremely difficult. Captured benefit estimates will, however, be made as a fraction of the potential benefits, and the procedure for estimation will be identified.

4.3.3 Social Benefits

Benefits, maximum or captured, are available to the operations that are studied, and can often be disposed of by the operations as they see fit.

If public funds provide the technology and the information that is the basis of the benefits, social benefits should be derived to support these public fund expenditures. The social benefit, most precisely the captured social benefit, is that part of the benefit captured by an operation which becomes available outside the operation to a social group or society at large, rather than the special interests of the operation.

The social benefit cannot be defined precisely for commercial operations since there is no control over the utilization of captured benefits within the operations. To a great extent, the social benefits that may actually be procurable are related to that definition of desirable which motivates an operation to implement in order to capture potential benefits. Desirability implies a very precise and personalized view of the economics of an operation within its operating context, and this cannot be established by general economic theory.

To attempt to define the social benefit requires that the interface and interaction between the operation and society be studied and evaluated. This interface is that between the economic structure of the operation and that of society. At each of the interfaces the interactions can create a transfer function that can modify the magnitude or temporal distribution of the benefits.

The social benefit can only be theoretically defined in terms of the accepted economic theory relating to the economic sector in which the operation functions. In this procedure, social benefit is purely theoretical and cannot be transformed into a captured social benefit.

In public operations, the captured social benefit may be difficult to define because of difficulty in assessing how a captured benefit may diffuse into society.

Social benefit and captured social benefit, while very desirable measures, will not be developed in this study because of the many conceptual, practical, and analytical uncertainties involved in the measures, and because of the complexity of its theoretical derivation.

4.4 Case Study Generalization Procedure

The case studies are comprehensive, in depth, evaluations of the potential benefits available from particularized operations. These operations are selected because they appeared to be promising benefit sources with generalization potential.

When case study benefits have been identified and evaluated, the case study results must be generalized or expanded to define the full extent of the benefits derivable from SEASAT information in a time stream over a planning horizon.

Generalization requires a careful formalization of the case study structure and its parameters which transforms SEASAT information to benefits. Generalization also requires that the class of operations, of which the case study is a representative member, be examined for each member of the class and to define how its structure and parameters may transform SEASAT information to benefits.

If the case study's transformational structure and parameters contain specializations not generally apparent in the class of operations, then reconciliation of the significance of these specializations must be determined before a valid generalization can be made.

A valid generalization of the case study then results from selecting from the general class of operation those additional operations for which the case study's specialization is not significant, or which can be interpreted, modified, or adjusted to be not significant.

Significance must be interpreted in terms of the SEASAT information utilized, the characteristics of the derived benefits and the generalization of the economic framework and context within which the benefits are derived. Significance is measured in terms of differences in the magnitudes of the parameters involved and is to a great extent judgmental, since it is not to be expected that operational forms and information employment will be repeated exactly as in the case study.

When a sub-class of the general class of operations has been selected for generalization, the benefit producing parameters must be adapted to remain representative of the operations, as the sub-class of operations is expanded to its maximum scope as a function of time.

The process of generalization may introduce benefits that are both U.S. or national benefits and non-U.S. or global benefits, but they are not always easily distinguishable. The benefits of a case study may also be national or global benefits. A national benefit would, in theory, be a benefit residing in an operation with U.S. operatives and a global benefit would reside in an operation with non-U.S. operatives. Such a dichotomy is not, in practice, easily decided upon because of international interdependence of most operations.

A global benefit may have a tenuous or concealed economic link to the U.S. national economy. Global benefit may result in a U.S. captured or social benefit, but it is not expected that such results can be, in general, determined.

Benefits, whenever possible, will be classified as national (U.S.) or global.

5.0 ECONOMICS OF THE MARITIME INDUSTRY

5.1 Overview and Definitions

In order to present the analysis in a consistent manner, this chapter will define the maritime industry and the numerous terms in the industry and the use of these definitions in the following sections.

The maritime industry encompasses all ocean going activities as opposed to inland waterway activity. The activity on the Mississippi River, for example, is not part of maritime activity, while ship movements between New Orleans and New York or between New Orleans and London are part of maritime activity. Shipping on the Great Lakes is not included unless it terminates or originates in a foreign country.

The numerous definitions of ocean going vessels often cause confusion to the layman. In general, it may be said there are only two types of vessels: Those which carry cargo and those which carry passengers.

Vessels are also cross classified by the schedule they follow as:

1. Liners (Regular)*
2. Tramps (Irregulars)
3. Tankers

A liner is a vessel which follows a regular route and schedule while a tramp is an opportunist which takes whatever cargo it can find. And a tanker usually operates by

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*Note that the term Liner does not imply "passenger liner," but relates only to the nature of the schedule followed.

a charter. The owner of the charter may or may not operate on a fixed route and schedule. For U.S. trade in 1970, the breakdown by this classification is illustrated in Table 5.1.

More detailed breakdowns of the general passenger/cargo split are numerous and vary in the number of categories. The major classification schemes which will appear in this study are related in Table 5.2. It is only necessary to define container vessels as ships designed to carry intermodal containers of cargo to be loaded to and from trucks. The definitions of the rest of the broad categories are found in the Glossary. The groupings of Department of Transportation Transoceanic (DOTTO) codes into four more aggregate categories is a scheme employed by Planning Research Corporation. These basic 19 categories are Transport Homogenous Groups (THG's). Each THG vessel type carries the same type commodities. These vessels are defined by their density (lbs./ft^3) and by the value per pound (in dollars) of the commodities they transport, [184, Volume I, p. III-58]. A breakdown of the world fleet as of December 3, 1972, according to the MARAD classification is given in Table 5.3, [118, p. 1].

Table 5.1 Classification Breakdown

1970	Total U.S.		U.S. Imports		U.S. Exports	
	Millions of lbs.	%	Millions of lbs.	%	Millions of lbs.	%
Liner	111,860	10.4	47,178	7.9	64,682	13.5
Tramp	603,347	56.0	228,401	38.2	374,946	78.2
Tanker	362,659	33.6	322,739	53.9	39,920	8.3
Totals	1,077,866		598,318		479,548	

Table 5.2 Vessel Classification					
	U.S. Maritime Administration (MARAD) Organization for Economic Cooperation and Development (OECD)	Department of Transportation (DOT) Planning Research Corporation (PRC)	Department of Transportation Transoceanic Code (DOTTO)		
			No.	Vessel Type	Code
Passenger	Passenger	Passenger		N/A	
Passenger & Cargo	Combination	*			
Cargo	Tankers	Bulk Liquid	1	Bulk Liquid	8
	Freighters	Container	2	Container, Reefer	1
			3	Container	2
			4	Container	3
			5	Container	4
			6	Container	5
			7	Container	6
	Bulk Carriers	Bulk Dry	8	Dry Bulk	10
			9	Dry Bulk	11
			10	Dry Bulk, Perishable	12
			11	Dry Bulk	14
			12	Dry Bulk, Perishable	16
		Break Bulk	13	Break Bulk	20
			14	Break Bulk	21
			15	Break Bulk	22
			16	Break Bulk	23
			17	Break Bulk	24
			18	Break Bulk	25
			19	Break Bulk	26
	LASH (Barges)***	**			

* Not broken out of other classifications by DOT and PRC
** Not ocean going
*** Lighter Aboard Ship

Table 5.3 World Merchant Fleet

WORLD TOTAL - ALL TYPES

OCEANGOING MERCHANT TYPE VESSELS OF 1,000 GROSS TONS AND OVER
SHOWING NUMBER, PERCENT, AVERAGE AGE, SPEED & DRAFT BY TYPE OF VESSELS, AND COUNTRY OF REGISTRATION

As of December 31, 1972

Country of Registry	Total					Type of Vessel: Combination Passenger & Cargo					Freighters					Bulk Carriers 2/					Tankers				
	Number of Ships	Percent of Total World Fleet	Average Age	Average Speed	Average Draft	Number of Ships	Percent of Total Combination	Average Age	Average Speed	Average Draft	Number of Ships	Percent of Total Freighters	Average Age	Average Speed	Average Draft	Number of Ships	Percent of Total Bulk Carriers	Average Age	Average Speed	Average Draft	Number of Ships	Percent of Total Tankers	Average Age	Average Speed	Average Draft
World - Total	21,009	100.0	12	14	27	860	100.0	21	16	21	12,029	100.0	13	14	24	3,539	100.0	8	14	32	4,581	100.0	11	14	33
Foreign	19,859	94.5	11	14	27	707	82.2	20	16	21	11,344	94.3	12	14	24	3,507	99.1	8	14	32	4,301	93.9	11	14	33
United States	1,150	5.5	22	16	30	153	17.8	27	17	25	685	5.7	22	16	29	32	.9	27	15	33	280	6.1	20	15	33
Privately-Owned	651	3.1	18	17	32	12	1.4	17	21	29	361	3.0	17	18	30	32	.9	27	15	33	246	5.4	18	16	34
Government-Owned	499	2.4	28	15	27	141	16.4	28	17	24	324	2.7	28	14	28	-	.0	-	-	-	34	.7	29	14	26
Argentina	155	.7	21	14	25	12	1.4	21	16	23	74	.6	21	14	24	12	.3	14	14	29	57	1.2	22	13	26
Brazil	233	1.1	14	14	24	6	.7	36	15	19	154	1.3	14	14	24	29	.8	13	13	28	44	1.0	12	13	25
British Colonies	100	.5	14	14	27	5	.6	24	15	19	51	.4	15	13	22	26	.7	13	14	29	18	.4	13	15	38
Bulgaria	110	.5	13	13	24	4	.5	13	15	16	62	.5	14	13	22	27	.8	10	14	27	17	.4	14	13	27
China (Communist)	272	1.3	21	13	23	22	2.6	29	13	18	199	1.7	21	13	24	21	.6	21	12	21	30	.7	16	12	23
China (Nationalist)	162	.8	12	15	26	6	.7	16	16	19	116	1.0	12	14	24	25	.7	9	15	33	15	.3	14	14	34
Cyprus	401	1.9	18	13	24	8	.9	31	16	25	326	2.7	18	13	23	38	1.1	17	12	25	29	.6	17	14	28
Denmark	297	1.4	8	16	27	8	.9	16	14	17	202	1.7	9	16	25	29	.8	5	15	33	58	1.3	7	15	35
Finland	213	1.0	11	14	23	6	.7	19	17	16	143	1.2	10	14	21	15	.4	10	13	25	49	1.1	14	14	30
France	427	2.0	10	16	29	12	1.4	15	20	23	219	1.8	11	16	25	64	1.8	9	14	31	132	2.9	10	15	37
Germany (East)	140	.7	11	15	25	5.	.6	20	18	25	111	.9	10	15	24	15	.4	12	15	30	9	.2	13	15	33
Germany (West)	797	3.8	6	16	26	6	.7	13	20	22	643	5.3	6	16	24	78	2.2	6	15	36	70	1.5	6	15	33
Greece	1,549	7.4	15	14	27	60	7.0	25	17	22	940	7.8	17	14	25	293	8.3	7	14	31	256	5.6	14	15	34
India	253	1.2	12	15	28	12	1.4	16	15	22	184	1.5	12	15	27	44	1.2	8	15	36	13	.3	10	15	35
Indonesia	139	.7	17	12	18	29	3.4	19	12	17	87	.7	17	12	19	7	.2	6	12	17	16	.3	16	12	21
Italy	625	3.0	16	14	27	58	6.7	20	18	22	223	1.9	19	14	23	136	3.8	11	15	33	208	4.5	15	14	28
Japan	2,210	10.5	6	14	27	32	3.7	11	16	16	1,217	10.1	7	14	24	525	14.8	5	14	33	436	9.5	6	13	32
Korea (South)	119	.6	14	13	24	1	.1	26	15	30	76	.6	16	12	22	18	.5	7	14	30	24	.5	12	14	27
Liberia	2,139	10.2	11	15	34	28	3.3	19	17	26	549	4.6	13	14	26	753	21.3	8	15	35	809	17.7	12	15	39
Netherlands	436	2.1	11	15	27	11	1.3	19	18	27	316	2.6	10	15	24	27	.8	9	14	32	82	1.8	12	15	33
Norway	1,188	5.7	8	15	32	31	3.6	12	18	19	419	3.5	11	15	24	362	10.2	6	15	36	376	8.2	8	15	36
Panama	887	4.2	18	13	25	32	3.7	25	16	23	546	4.5	19	13	22	111	3.1	16	13	27	198	4.3	16	15	34
Philippines	170	.8	17	14	23	21	2.4	11	15	17	111	.9	16	14	24	9	.3	13	14	29	29	.6	18	12	22
Poland	253	1.2	9	15	25	2	.2	19	14	20	191	1.6	9	15	24	56	1.6	8	14	27	4	.1	15	15	30
Portugal	114	.5	15	15	24	19	2.2	19	16	23	67	.6	15	14	23	6	.2	9	14	29	22	.5	12	14	27
Singapore	176	.8	16	14	23	18	2.1	22	13	21	138	1.1	16	14	23	6	.2	10	14	34	14	.3	15	13	24
Somalia	148	.7	18	14	26	2	.2	23	13	20	122	1.0	18	14	25	13	.4	14	14	31	11	.2	17	14	31
Spain	423	2.0	14	14	24	38	4.4	25	16	21	230	1.9	16	13	20	46	1.3	6	14	31	109	2.4	10	14	29
Sweden	337	1.6	8	16	29	5	.6	10	19	22	175	1.5	9	17	26	79	2.2	7	15	35	78	1.7	6	14	33
U.S.S.R.	2,140	10.2	10	14	22	79	9.2	18	15	18	1,482	12.3	10	14	22	135	3.8	14	12	22	444	9.7	9	13	23
United Kingdom	1,627	7.7	10	15	30	45	5.2	17	19	26	819	6.8	10	15	26	326	9.2	8	14	32	437	9.5	9	15	37
Yugoslavia	187	.9	11	15	26	11	1.3	13	17	20	139	1.2	12	15	25	20	.6	6	15	33	17	.4	9	14	27
All Others	1,432	6.8	14	14	24	73	8.5	22	15	20	1,013	8.4	13	14	23	156	4.4	11	13	26	190	4.1	13	14	27

1/ Includes the following countries with less than 100 merchant type ships (1,000 gross tons and over) under their registry: Albania, Algeria, Australia, Austria, Bangladesh, Belgium, Burma, Canada, Chile, Colombia, Costa Rica, Cuba, Czechoslovakia, Dominican Republic, Ecuador, Ethiopia, Ghana, Guatemala, Guinea, Honduras, Hungary, Iceland, Iran, Iraq, Ireland, Israel, Ivory Coast, Jamaica, Kenya, Korea (North), Kuwait, Lebanon, Malagasy, Malaysia, Maldives, Mexico, Monaco, Morocco, Nauru, New Zealand, Nicaragua, Nigeria, Pakistan, Peru, Rumania, Saudi Arabia, Senegal, Sierra Leone, South Africa, Sudan, Switzerland, Tanzania, Thailand, Tonga, Trinidad-Tobago, Trucial States, Tunisia, Turkey, Uganda, United Arab Republic, Uruguay, Venezuela, Vietnam (South), Zaire, and Zambia.

2/ Includes Bulk/Oil, Ore/Oil, and Ore/Bulk/Oil Carriers.

NOTE: Percentage figures may not be additive due to rounding.

The units of measure commonly used to describe the vessel and its content are:

1. Draft (in feet) - the depth to which the vessel extends below the surface.
2. Deadweight tons (or deadweight in long tons) usually presented as the payload to a certain draft when speaking of a ship's carrying capacity.
3. Long ton - 2240 lbs. (=1.016 metric tons)
4. Metric ton - 1000 kilograms (=2,204.724 lbs.)
5. Short ton - 2000 lbs. (=.907 metric tons)
6. VLCC - Very Large Crude (oil) Carrier, i.e., between 100,000 and 250,000 deadweight.
7. ULCC - Ultra Large Crude Carrier, i.e., above 250,000 deadweight tons.
8. Knots - nautical miles per hour (1 nautical mile = 1.1508 statute miles)

The costs involved in the construction of a vessel vary greatly depending on the type of vessel involved. In calendar year 1973, there were 21 ships of 9 types completed in the United States at an average cost of $23.3 million with a low cost of $7.0 million and a high cost of $50.0 million. See Commerce News [36 , p.7]. Tankers are usually at the upper end of the scale. For example, Seatrain Shipbuilding Corporation has three 225,000 deadweight ton (dwt) tankers under construction which will cost between $57.3 million and $70.6 million by the time they are completed between now and 1976, Commerce News [36 , p.5].

Using 1972 figures, the Maritime Administration estimated that the costs of shipbuilding could be broken down as:

	%
Steel	17.2
Other Material	34.0
Labor	42.0
Overhead	6.8
Total	100.0

These figures are from the U.S. Maritime Administration [126, p. 29]. Operating expenses, likewise, exhibit great variation. Costs and productivities can be found in Planning Research Corporation [184 , Volume II, Section IX] for the major cargo carriers: Bulk carriers, breakbulk carriers, container ships, LASH, and tankers.

Using 1974 dollars, a 120,000 (dwt) tanker could cost $3,980,000 to operate per year. This would be broken down approximately as in Table 5.4.

These figures are derived from the Ocean Data Systems, Inc. data which were compiled as part of this study. The principal costs, besides the capital cost, are Crew (40.2%), Fuel (36.1%) and Insurance (12.0%).

Actually the insurance figure is deceptively low because there is a certain amount of self-insurance. The order of magnitude of self-insurance to premium paying insurance may be 2 or 3 to 1. Clingan and Alexander [163 , p. 77] indicate that the portion of the operating cost of a 200,000 dwt tanker which goes to insurance is more like 45% of the total. Therefore, the conventional accounting of shipping operations when it is done on a single ship basis may underestimate the true operating cost by between 20% and 35%, due to omission of the self-insurance costs.

Table 5.4 Capital and Operating Costs of a 120,000 dwt Tanker

Capital Cost (Annual Amortization of 20%)	$29,640,000 (5,928)	
Operating Costs, Total	3,980	(100.0%)
of which: Crew	1,600	(40.2%)
Stores & Supplies	122	(3.1%)
Subsistence	34	(0.9%)
Main. & Repair	243	(6.1%)
(12.0%) Insurance On: Hull & Machinery	342	(8.6%)
(12.0%) Insurance On: P & I	108	(2.7%)
(12.0%) Insurance On: Cargo	27	(0.7%)
Overhead	65	(1.6%)
Fuel	1,439	(36.1%)

The basic insurable categories are: Hull & Machinery, which is the physical structure of the vessel plus its equipment; cargo, the contents of the vessel; and P & I, personnel and indemnity, the liability portion of the insurance.

With this brief explanation of the maritime industry and some physical and cost aspects, the next few pages begin the overview of the economics of the industry.

The demand for shipping is essentially a derived demand. That is, the need for shipping can be deduced or derived from the demand for commodities which are to be shipped.

If the amount of exports of a particular good which will flow from New York to London in one year is known, it requires only a straight forward calculation to determine the shipping requirements. It is necessary to know:

1. The type of commodity demanded for export or import
2. The amount of the commodity (in long tons)
3. The shipping distance between the ports

It is not sufficient to know just the amount and distance of the traded commodity since the type of commodity may dictate special shipping designs for its economical transport by ocean. The basic unit of shipping demand for a specific type vessel (specific to the type cargo it is designed to handle) is the ton mile (a long ton nautical mile). If a ship must carry 30 tons over a distance of 3,000 miles, there is a shipping demand of 90,000 ton miles. To determine further the number of ships required, the capacity and speed of that type ship must also be known.

In the balance of this report, the demand for shipping ton miles will be the terminology employed rather than the number of ships demanded. It is not necessary to perform the extra calculations since our purpose is to estimate the impact of ocean condition forecasting on the cost of goods which are shipped, rather than on the number of ships required. The prime concern is ultimately the transportation of the goods to the consumer more cheaply.

The capital and operating costs of supplying shipping services have been broken down above. For illustration, the supply and demand aspects are presented in Figure 5.1. The operating costs which go to insurance premiums are separated out since they provide the revenue on which the marine insurance

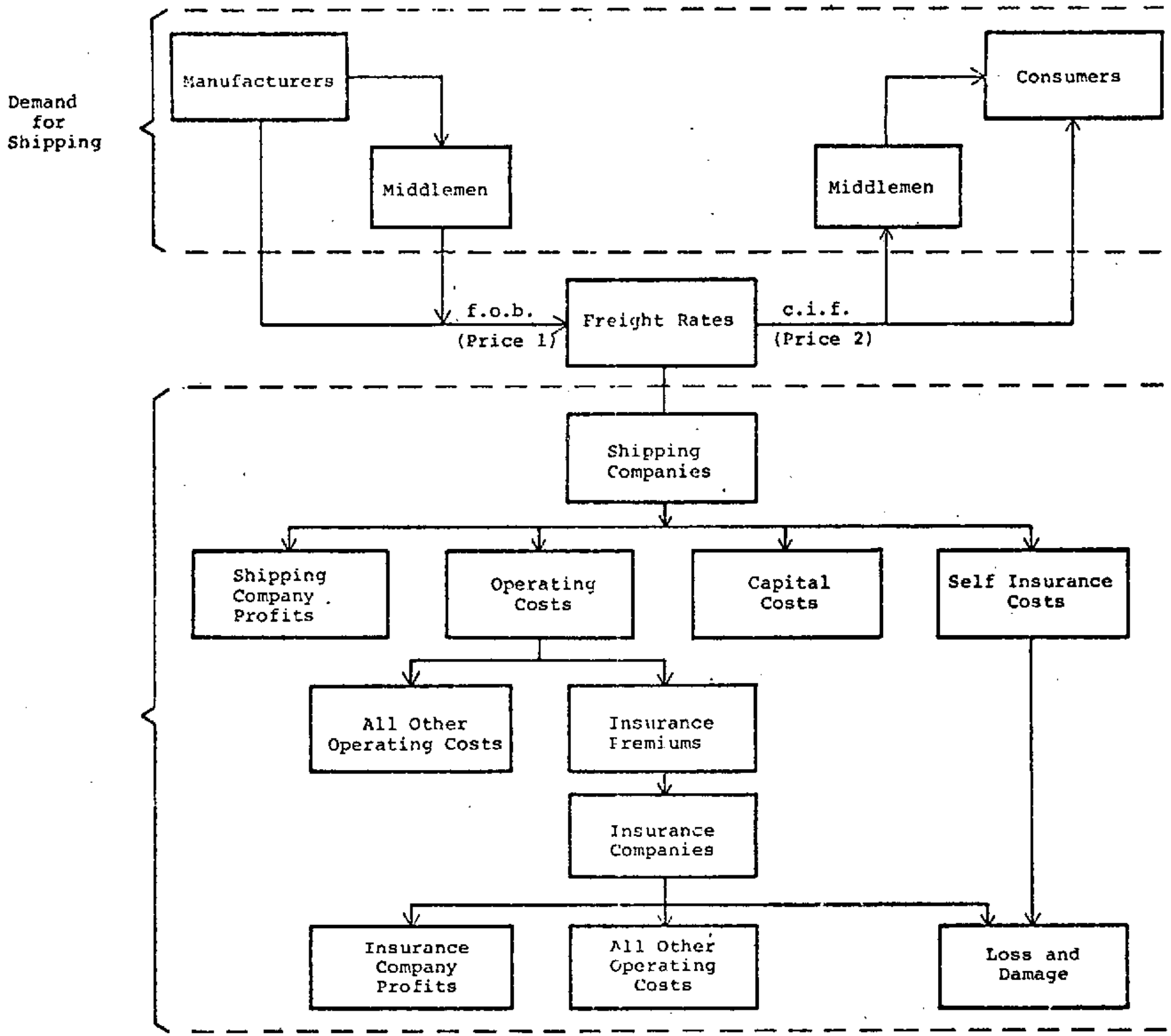


Figure 5.1 Maritime Industry Economics Overview

industry exists. And the marine insurance industry is important to this study because losses and damage suffered by ships through inadequate or faulty forecasts of ocean conditions will be paid for by the insurance companies (to the extent that vessels are not self-insured).

Freight which flows from manufacturers to consumers over the oceans comes to the shipper at price 1 (f.o.b. or free on board). The commodity is delivered to the other end of the marine link at price 2 (c.i.f. or cost, insurance and freight where cost is equal to f.o.b.). The spread between f.o.b. and c.i.f. is on average between 6% and 9%. This means that the ocean transportation costs make up between 6% and 9% of the price which the consumer pays for the commodity.

While competition within the shipping industry is keen, competition between the airlines and shipping is not. OECD estimates for 1970 show tonnage movements inter-regionally by air transport for its members was 0.1% of the total tonnage. This insignificant competition from airlines means the demand for shipping services in aggregate are inelastic relative to freight rates. Fluctuations in freight rates which add only 6% to 9% to the ultimate price of the commodity will not impact on the demand for shipping.

But the freight rates, which provide the lifeblood of the maritime industry, can be expected to impact on the supply of shipping significantly in the long run. The maritime industry's vitality and existence depend upon the behavior of the freight rates.

The next four sections discuss, respectively, the marine insurance industry, the determination of freight rates, the impact of technology on insurance rates and freight rates, and the quantification of the economic benefits to be derived from better forecasting.

5.2 Maritime Insurance Rate Economics

The countries which together constitute the maritime insurance market are England, Germany, Japan, Switzerland, the Scandinavian countries and the United States. England's share of the market is larger than the sum of the other countries' shares. In 1972 inland marine insurance premiums in the U.S. amounted to $975 million while maritime shipping insurance premiums amounted to $550 million according to Insurance Facts 1973 Edition, Insurance Information Institute, New York, New York, 1974. England's maritime shipping insurance premiums were four to five times the size of the U.S. volume.

It is difficult to find economic analyses and assessments in the maritime insurance field because of the scarcity of comparable data since ships vary in so many ways. Quoting spokesmen for the American Hull Insurance Syndicate, Schumacher and Pettersen [102, p. 3].

> "In the case of life insurance, the actuarial sciences have almost completely displaced the element of uncertainty so far as the underwriter is concerned. With the insurance of ships, however, it is a different matter because there simply are not that many vessels in the world to develop a matching statistical base of equal credibility. In hull insurance, then, the uncertainty is not eliminated, but merely lessened. For this reason, the insuring of ships is recognized to be a form of high-risk underwriting."

Among the sources of data, however, which shed some light on the maritime insurance industry are the following: the American Bureau of Shipping, _Record of the American Bureau of Shipping_, New York, and Lloyds' _Registry of Shipping_, London, (the ABS and Lloyds are the two principal ship classification organizations in the world); aggregate data for the U.S. are found in _Insurance Advocate_ and _Best's Aggregates and Averages_ and in the Annual Reports of the American Hull Insurance Syndicate (AHIS) and its technical branch the United States Salvage Association (USSA) which also conducts and publishes the results of surveys of casualty and damage data; the U.S. Maritime Administration which has a large repository of insurance and other shipping information for the U.S. fleet to conduct its subsidy program; U.S. Coast Guard, _Annual Statistics of Casualties_ collected by the Office of Marine Casualty Statistics; casualty records of the Navy Safety Center, Naval Air Station, Norfolk, and the Marine Index Bureau, Inc., New York, New York; the Insurance Company of North America, Inc., _Ports of the World_, Philadelphia (contains 20 year world loss summary data); casualty and repair reports of Lloyds' for the world vessels; the data base on vessel casualties of the United Nations organization, The Inter-Governmental Maritime Consultive Organization, Maritime Safety Committee. For one of the few macro analyses of marine insurance see Alan P. Kirman, _A Report to the U.S. Maritime Administrator on the Marine Insurance Industry_, U.S. Dept. of Commerce, Washington, October 1970.

The Kirman study, using 1969 data, found the following breakdown of premium payments in merchant shipping:

	Net Premiums Paid	Loss Ratio*
Hulls	$ 50 Mil	68%
P&I	30	89%
Cargo	116	
Exports		87%
Imports		59%
Other		43%

$$\left({}^{*}\ \text{Loss Ratio} = \frac{\text{Claims Paid or Pending}}{\text{Net Premiums Paid}} \times 100 \right)$$

The American Institute of Marine Underwriters write 98% of marine policies in the U.S. There is, naturally, large yearly variation in these figures.

The high loss ratio for P&I has caused many American companies to lose interest in it. As a result most of this insurance business has shifted to London where the United Kingdom Mutual Steamship Association (UKMSA) Ltd. insures approximately one third of the world's ocean tonnage for P&I. The UKMSA is a member of the London group which is composed of 15 P&I Associations which insure 80% of the world's tonnage for P&I, (Hazards of Maritime Transit, page 79). P&I associations are operated on a mutual, nonprofit basis by owners and operators of the bulk of world tonnage. The breakdown of P&I payments in the Kirman study were:

50% claims for crew liability
25% claims for cargo
25% miscellaneous

Special problems of liability arise with respect to oil spill liability. As Table 5.5 shows, oil shipments, whether measured by tonnage or ton-distance, account for over half of world shipping.

The present oil liability insurance plans include The International Convention on Civil Liability for Oil Pollution Damage, supplemented by the Convention on the Establishment of an International Fund for Compensation for Oil Damage which calls for coverage up to $35 million at present with provision for extension to $70 million. There are also numerous oil industry insurance programs such as TOVALOP, ITIA, P&I Clubs, CRISTAL, O.I.L., and the Water Quality Insurance Syndicate. These schemes cover 90% of free world tonnage. See Hazards of Maritime Transit [163, p. 70] which also contains a brief description of each of these schemes.

A final area to be discussed is the marine insurance procedure followed in the U.S. by the American Hull Insurance Syndicate. Insurance premium payments are set on a fleet by fleet basis, occasionally on a class type basis (e.g. containership of a certain size), but never on a route by route basis. The running record of payments for a fleet for the last five years is maintained and up-dated every year, starting approximately 2-1/2 months before the annual policy expiration date. This is called an experience rating model. After a review of this record and consideration of such external factors as inflation (i.e. a cost of repair index) the premium payments for the fleet are adjusted accordingly, Schumacher [103].

Table 5.5 Oil Versus Other World Trade

	Million Tons	Thousand Million Ton-Miles
Crude Oil	1,068 (41.4%)	6,520 (55.7%)
Oil Products	247 (9.6%)	900 (7.7%)
Other Trade	1,265 (49.0%)	4,275 (36.6%)
World Totals	2,580 (100.0%)	11,695 (100.0%)

Source: OECD [121, page 22]

The syndicate maintains that it cannot perform the research required on such things as implementation of safety devices and new technologies and therefore must rely on experience in setting rates. In the case of a totally new ship such as the Ultra Large Crude Carriers (ULCC) they resort to an evaluation questionnaire and a class rating model until an experience rating model can be developed. The evaluation questionnaire was developed for the large tankers and has been revised several times. But questionnaires are now being developed for dry cargo vessels as well. The rating models are models developed from the experience models of existing ships in a similar class. For example, new containerships were rated by comparison to similar size dry cargo vessels and the Very Large Crude Carriers were initially rated by comparison against the small tankers. For a more detailed discussion of these procedures see Schumacher, [102].

5.3 Freight Rate Economics

There are several areas of analytic development pertaining to the setting of freight rates and the impact of freight rates on the structure of the maritime industry and the general economics of the trading partners.

Starting at the broadest end of the spectrum there are considerations such as the impact of decisions by international and national political organizations on the competitiveness of the freight rate market. The United Nations recently adopted a Code of Conduct for Liner Conferences. The Code will become effective on a voluntary basis if it is ratified by 24 countries—which is most likely.

Under the Code the "40-40-20 principle" would be followed: for trade between two countries the respective merchant fleets would each carry 40% and 20% would be carried by the fleets of third countries. The Code was adopted to assist developing countries in the creation of merchant fleets. Since the Code is not mandatory and since it was supported mainly by developing countries, it is not expected that there will be a major change in the shipping practices between developed countries although several of these countries did vote in favor of the Code. The United States voted against adoption despite existing cargo sharing agreements with some Latin American countries [157, p. 5].

At the present time the United Nations Conference on the Law of the Sea is meeting in Caracas, Venezuela. At stake are resolution of two points relevant to the free transit of ships. The first point is the determination of the limit to which a country's sovereignty extends off its coastline. Various claims make the distance 3, 12 or even 200 miles. The second point relates to who shall control passage through the major straits. Obviously the solutions can affect freight rates which are distance dependent.

In the realm of national interest are such facets as the political prestige and economic independence associated with a large merchant fleet. Countries may adopt subsidy programs and regulations requiring use of their fleet. In the U.S., the Jones Act requires that ocean cargo from one U.S. port to another U.S. port be carried on U.S. ships.

Similar national considerations are encountered in the areas of balance of payments and development. Receipt of foreign exchange earned by ocean transport may be very important considerations in shipping countries such as Denmark, the Netherlands, Norway, Sweden, and the United Kingdom. An example of the relationship between ocean freight rates and the current account of the balance of payments may be seen in the econometric work of Driehuis [122]. These considerations may be more important for developing countries, which have had worsening terms of trade, than for developed countries. See Richards [232].

The basic macro analysis of freight rates at the world shipping industry level may be seen in such works as Koopmans [154], Tinbergen [158], Dreihuis [122], Ferguson [153], Metaxas [181], Young [7], and Bennethan and Walters [207]. Brief surveys are to be found in Young, Appendix B, Ferguson, Dreihuis, and Bennathan and Walters. Before giving a representative model of this type by Dreihuis it is necessary to explain conference operations.

The shipping conference is an organization of two or more lines whose purposes are the elimination of price competition among themselves and the provision for regular schedules from port to port. The advantages of the conferences are reported to be the rate stability they achieve and the dependability of sailing. Conferences came into being at the end of the 19th century and there are now about 120 conferences in the U.S. ocean trade. For a list of these conferences see U.S. Dept. of Commerce [101, Appendix A]. The basic disadvantage, of course, is the lack of price competition engendered by the conferences. In addition to limiting price competition the conferences engage in exclusive patronage agreements such as dual contracts by which a shipper can gain a rebate of as much as 15% if he commits all or a fixed portion of his shipments to conference vessels.

However, the conference liners face competition from the independent liners and from tramp vessels (who do not follow a regular schedule as liners do) whose rates are usually lower. There is some debate as to the long run goals which the conferences seek to achieve by their pricing policies and other actions. It is sometimes claimed that they seek long run profit maximization with the constraint that profits in the short run should not be great enough to attract substantial competition. For a discussion of this and other goals see Sturmey [124].

The conferences publish their rates in tariffs. The tariff is defined as a schedule of articles of merchandise with the rates of duty to be paid for their importation or exportation. Conferences handling U.S. trade are required by law to keep their rates available to the public. The rate charged depends on such variables as weight, volume, and value of the merchandise, distance (Rates rise rapidly and level off quickly, rising only gradually, then, when plotted against distance. Thus a 1000 mile shipment is less than twice as expensive as a 500 mile shipment).

Following is a simple model of the liner shipping market developed by Dreihuis [122]:

$$\bar{d}_\ell = \phi_1 (e)^{\lambda_1 t} \left(\frac{\bar{p}_\ell}{\bar{p}_t}\right)^{-\alpha_1} (\bar{b})^{\alpha_2}$$

$$\bar{p}_\ell = \phi_2 (e)^{\lambda_2 t} (\bar{k})^{\beta_1} (\bar{c}_\ell)^{\beta_2}_{-v_1} (\bar{p}_t)^{\beta_3}_{-v_2} (\bar{z})^{\beta_4}_{-v_3}$$

$$\bar{c} = \left(\frac{\bar{d}_\ell}{\bar{y}_\ell}\right)$$

where

$\bar{d}_\ell$ = demand for liner tonnage

$\bar{p}_\ell$ = general level of liner freight rates

$\bar{p}_t$ = general level of tramp freight rates

$\bar{b}$ = volume of world dry cargo trade

$\bar{k}$ = operation costs in liner shipping

$\bar{c}_\ell$ = rate of capacity utilization in liner shipping

$\bar{z}$ = variable representing expectations of liner ship-owners.

$\bar{y}$ = available capacity in liner shipping

v_1, v_2, v_3 = unknown lags

t = year

The following may be interpreted as

$$\lambda_1,\ \lambda_2,\ \alpha_1,\ \alpha_2,$$

$$\&\quad \beta_1,\ \beta_2,\ \beta_3,\ \beta_4 \quad = \text{elasticities (see glossary)}$$

$$\phi_1,\ \phi_2 \quad = \text{scaling factors}$$

The estimation results indicated that this model could satisfactorily explain freight rates by changes in operating costs, unused capacity (with a half year lag), world market prices of raw material (with a lag of three quarters) and the difference between percentage changes in liner freight rates in the previous year as an approximation of expectations of liner ship-owners, Dreihuis [122, p. 118].

The data required for the estimation of the coefficients of such models are often difficult to obtain, especially freight rates or freight rate indices. A survey reveals the following principal sources of freight rate information: Drewry, Shipping Consultants, Ltd., Shipping Statistics and Economics, monthly, London; Norwegian Shipping News, Oslo; Organization for Economic Co-operation and Development, Maritime Transport, annual, Paris; Fairplay, Annual Returns Issue (Rates comparison series in Annual Returns Section), London; John I. Jacobs & Co., Ltd., World Tanker Fleet Review (worldscale tanker rates); the liner freight rate index compiled by the West German Ministry of Transport and the Norwegian tramp freight rate index, published in the U.N., Monthly Bulletin of Statistics, New York.

There are also a variety of governmental publications and trade association journals which provide world coverage data in regular series for a number of variables necessary in freight rate models. One example from each of these two categories are: U.S. Department of Commerce Maritime Administration, A Statistical Analysis of the World's Merchant Fleet, annual, Washington (showing age, size, speed and draft by frequency groupings); and Seatrade, a magazine published monthly by Benham & Company, Ltd., England, which includes spot tanker rates (from E. A. Gibson, shipbrokers, London), dry cargo voyage freight rates and scrapping prices (from R. S. Platou, Oslo) and orders and completions of new tonnage (from Lloyd's Registry of Shipping), and laid-up tonnage (from U. K. Chamber of Shipping, London).

In addition to the above mentioned macro studies of freight rates there are micro studies which emphasize the cost structure and supply consideration for individual firms or ships. They focus on such aspects as time at sea versus time in port or turn-around time, and integration of individual ships into a transportation system via intermodal improvements. Examples of these type studies may be seen in Abrahamsson [204], Goss [162], Sturmey [124], and Kendall [91].

5.4 Technological Developments

Technological developments in ocean shipping respond to demand factors (such as the growing demand for oil and the mammoth new ships needed to carry the oil and the totally new demand for Liquid Natural Gas (LNG) and the specialized ships to carry it) and supply factors (such as the competitive necessity to cut costs and supply transport services at a higher level of productivity) and many non-economic considerations among which are political and environmental considerations.

On the supply side the search for a competitive advantage can sometimes lead to a technological innovation of dramatic proportions such as the switch from sail to steam. Equally dramatic changes occur on the demand side as illustrated by the development of the internal combustion engine and the subsequent growth of ocean trade in oil to more than half of world trade. Demand induced technological innovations are almost impossible to predict since they depend on the interrelationship of science, regional and market developments, consumer tastes, and fortuitous inventions and discoveries of new products and needs.

The less dramatic and continuous technological developments which lead to the steady productivity gains necessary to the survival and health of any industry are numerous and often well documented by the many private trade association journals and government journals. A thorough documentation of the history of technological developments in maritime shipping may be found in Robert Greenhalgh Albion's Naval and Maritime History: An Annotated Bibliography, 3rd edition, Mystic, Connecticut, 1968. A concise statement of U.S. experience may be found in Richard W. Barsness's "Maritime Activity and Port Development in the U.S. Since 1900: A Survey," The Journal of Transport History, 2 (3), February 1974, pp. 167-184. Besides the specialized journals the U.S. Maritime Administration funds technical studies and makes the results available to the public. For example, the list of Maritime Administration research and development contracts awarded during fiscal year 1973 may be seen in MARAD 1973 [108, p.74]. MARAD is the annual report of the Maritime Administration and it also contains the best available summary for each year of technological developments in the U.S. maritime industry.

Following Frankel in Hazards of Maritime Transit [163], technological developments may be grouped in any one of five areas: navigation and control of the sea lanes; port approaches, maneuvering and docking; environmental effects;

offshore developments, exploration, and exploitation (floating and rigid rigs); and recreational and commercial fishing. In each of these areas are found a continuous stream of technological developments. A representative list of these developments and the time horizon within which they will probably be realized is given in Table 5.6.

In counterbalance to these areas of substantive progress there are areas in which voids exist where a significant need for improvement has been revealed. Some of these voids, in both technical innovation and regulatory innovation, are listed in Table 5.7.

Use of SEASAT weather information may be useful in filling the void in accuracy of navigational control. This area is especially important because of the higher proportion of loss and damage, much of which is weather related. As Frankel, Hazards of Maritime Transit, [163 , p.58], notes

> Grounding and collision account for over 50 percent of all ship losses and oil spills. Foundering and hull failure are usually the result of operating conditions and/or failure in ship design.

This is borne out by the following figures from Hazards of Maritime Transit [163, p. 54]:

Cause	1956-1970 % Loss of Shipping	% of Oil Spill Caused
Grounding	43.6	48.4
Foundering	18.0	5.6
Hull Failure	2.0	27.0
Fire-Explosion	15.3	1.0
Collision	12.0	6.7
Contact Damage	4.5	0.5
Machinery	1.2	-
Missing	1.9	-
Other	1.5	3.0
	100.0	100.0

Table 5.6 Ocean Transportation Technology Forecasts

A. Predicted as Realizable by 1980

- Anti-collision and anti-grounding devices
- Oil spillage containment and clean-up techniques
- Oily water separator
- Continuous and automated unitized cargo (pallet or container)
- Loader/unloader
- Detachable lifesaving bridge and/or deckhouse structure
- Completely automated propulsion plants
- Completely automated bulk cargo loading/unloading systems
- Completion of oceangoing trimaran vessel
- Completion of oceangoing surface effect ship
- Completion of first 750,000 dwt tanker
- Development of submerged tanker terminal with bottom loading/unloading system
- Development of marine gas turbine with specific fuel consumption of 10.42 lbs/SHP-hr
- Development of effective smoke emission device for ships
- Development of truly effective oceangoing, detachable tug-barge or barge-ship coupling system
- Draft reducing device for mammoth tankers
- Sea traffic system controls and automatic navigation system
- Automatic ship mooring and docking systems
- Catamaran containerships
- Semisubmerged catamaran ships
- Effective tanker safety (fire, explosion, etc.) system
- Floating offshore container terminals
- Superconducting ship power transmission system

B. Predicted as Realizable in the 1980's

- One million ton tanker
- Automatic port and harbor navigation and maneuvering system
- Large oceangoing surface effect ship
- Fuel cell ship propulsion system
- Completion of first ship with batteries for propulsion
- Completion of submarine tanker
- Ships built with automatic 'cold' steel joining techniques
- Completion of unmanned merchant ship
- Completion of tanker loading-unloading system without hose connection
- Economic nuclear marine propulsion
- Overland ship transfer systems
- Inflatable-deflatable ships

Source: Hazards of Maritime Transit [163, p.51]

Table 5.7 Voids in Ocean Technology and Forecast

A. Voids in technology include:

- Accurate navigational control
- Maneuverability and stopping
- Defined controlled sealanes
- Segregation of shipping by size and speed
- Docking control (automated)
- Collision avoidance systems (automated)
- Continuous predictive bottom (sonar) scanning for grounding prevention
- Unmanned machinery spaces
- Automated life saving devices (such as self-launching boats and personnel transfer devices)
- Automated damage control
- Ballast/cargo segregation
- Programmed cargo planning and transfer
- Automated maintenance diagnostics
- Automated logging

B. Voids in regulation which may govern future approaches to regulatory improvements include:

- Environmental protection regulation which is achievable and controllable
- Control of shipping traffic
- More exacting qualification and training requirements for operators
- Assignment of shipping lanes
- Mandatory collision avoidance system and/or procedures
- Regulations of safety standards, including advanced life saving methods
- Regulation of automation and control schemes
- Agreement on coastal zone management and jurisdictional issues

Source: Hazards of Maritime Transit [163, p.52]

While there are a number of micro studies (i.e. studies of individual ship operations), some of which were alluded to in the previous section, which examine productivity questions, there is a notable dearth of macro studies dealing with productivity trends in the ocean shipping industry taken as a whole. This undoubtedly stems from the previously mentioned limited number of ships in the world of comparable capability and mode of operation and the lack of common economic data in cases when there are a sufficient number of comparable ships. Progress is being made by such international agencies as the United Nations and the Organization for Economic Cooperation and Development in developing a maritime transport industry data base. Analytic macro economic techniques have already been applied in the area of transportation economics to examine the questions of what new technology means to productivity and with what lag new technologies will be implemented. An example of this type of analysis for the U. S. railroad industry may be found in Edwin Mansfield's "Innovation and Technical Change in the Railroad Industry," Transportation Economics, New York: National Bureau of Economic Research, 1965.

5.5 Economics of Weather Forecasting

The chief sources of weather data, forecasting and research in the United States are the National Oceanic & Atmospheric Administration (NOAA) and the Environmental Science Services Administration (ESSA), both within the Department of Commerce and the Department of the Navy's United States Naval Oceanographic Office within the Defense Department. Miscellaneous weather related activities are carried out in various other government agencies such as the United States Coast Guard within the Department of Transportation and the Department of the Army and the U.S. Air Force within the Defense Department. These other activities include such procedures as weather mapping of the oceans and distribution of weather forecasts.

Individual ships on the world's oceans report weather conditions twice daily to NOAA. NOAA in turn amalgamates the reports, combines the reported data with historical data, analyzes and forecasts ocean conditions, and distributes the data to government agencies and private concerns. Among the government agencies which make extensive use of NOAA's services are the United States Coast Guard and the Navy's Fleet Numerical Weather Central (which routes United States Navy ships). Private concerns which use the NOAA services extensively for weather routing of ships are

1. Allen Weather Corporation, New York City
2. Bendix Commercial Service Corporation, New York City
3. Weather Routing, Inc., New York City
4. Pacific Weather Analysis Corporation
5. Ocean Routes, Inc., Palo Alto, California

Research in weather forecasting of concern to this study is being done by the National Environmental Satellite Service (NESS) within NOAA, by the Naval Research Laboratory in Washington, D.C., the Environmental Prediction Research Facility in Monterey, California, by the Environmental Research Laboratory of NOAA in Miami, Florida, and by the U.S. Weather Bureau.

At the international level the United Nations' World Meteorological Organization is coordinator of the World Weather Program. In this role the World Meteorological Organization is working with the International Council of Scientific Unions on what has been described as the largest and most complex international scientific experiment ever undertaken, Mariners Weather Log [224, p.240].

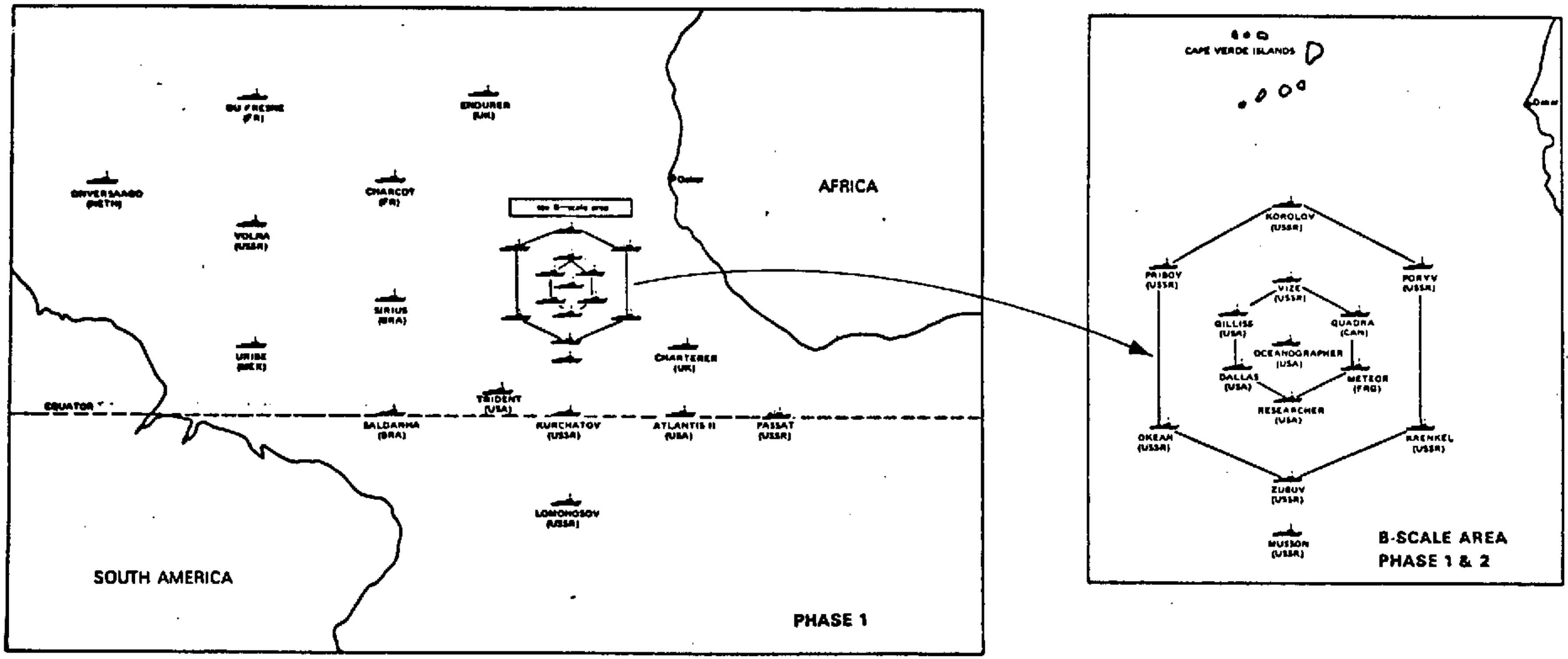
The study, called the Global Atmospheric Research Program -- Atlantic Tropical Experiment (GATE), has as its main goal to

> collect the massive quantities of simultaneous observations required to enable scientists to understand tropical weather phenomena, describe them in mathematical terms, and develop improved models for computer weather forecasting. [224,p.251]

To accomplish this, the study is being conducted for 101 days, from June 15, 1974, to September 23, 1974, and involves 38 ships, over 60 buoys, about 1000 land stations, and six types of satellites (the Soviet Union's Meteor satellites and the United States' SMS-A,ATS-3, Nimbus-5, Defense Meteorological Satellites, and NOAA-2 and NOAA-3). They are being deployed over the tropical Atlantic as illustrated in Figure 5.2 to collect data from the top of the atmosphere down to 5,000 feet below the surface of the sea. The ships of the 10 participating nations will be stationed 300 to 600 miles apart except for a more concentrated zone off the West African coast. This concentrated zone is also illustrated in Figure 5.2.

The project is being directed from Dakar, Senegal and the United States participation is being coordinated by NOAA through its ad hoc United States GATE Project Office.

The results of research efforts such as those mentioned above are found in a great variety of publications. Among the more important basic reference sources for data and research results are: the United States Weather Bureau, Department of Commerce, Climatological and Oceanographic Atlas for Mariners and the United States Navy, Department of Defense, Marine Climatic Atlas of the World; the Environmental Science Services Administration Technical Reports, Weather Bureau Series; the Mariners Weather Log published monthly by the Environmental Data Service of NOAA; and United States Navy Oceanographic Office, The Gulf Stream, monthly summary.



Source: Mariners Weather Log [224, p. 251].

Figure 5.2 Map of GATE Study Coverage Area

The type of data and research mentioned above assist in the development and implementation of weather forecasting models. The two basic pure models are the historical model and the mechanistic model. Estimates may be made deterministically or statistically (i.e. with a stochastic element or error term) by either method. The historical model relies on past weather information to make forecasts while the mechanistic models rely on present observations to make forecasts. In actual practice a hybrid is usually relied upon. Principal emphasis is placed on mechanistic methods for forecasts up to three or four days and historical methods are increasingly relied upon for forecasts beyond four days.

The accuracy of the weather forecast depends on how carefully the weather is defined. There is no set criteria upon which measures of accuracy are based. A measure of accuracy, be whatever criterion is selected, may range from 0.0 (always wrong) to 1.0 (always correct) over a given forecast horizon. This is illustrated in Figure 5.3. Improvements in forecasting system procedures (shortening the time between when data collection begins and when the forecast is made), data quality and quantity, and analytic forecasting models. In general an attempt is being made to eliminate the shaded area in Figure 5.3.

However, the benefits of eliminating the shaded area must be weighed against the cost of eliminating it. A systematic way of performing such an economic analysis was developed by J.C. Thompson and Richard R. Nelson and Sidney G. Winter of the RAND Corporation. The best explanations of this approach may be found in J.C. Thompson, "Economic Gains from Scientific Advances and Operational Improvements in Meteorological Prediction," Journal of Applied Meteorology, March 1962, pp. 12-17, and in Richard R. Nelson and Sidney G.

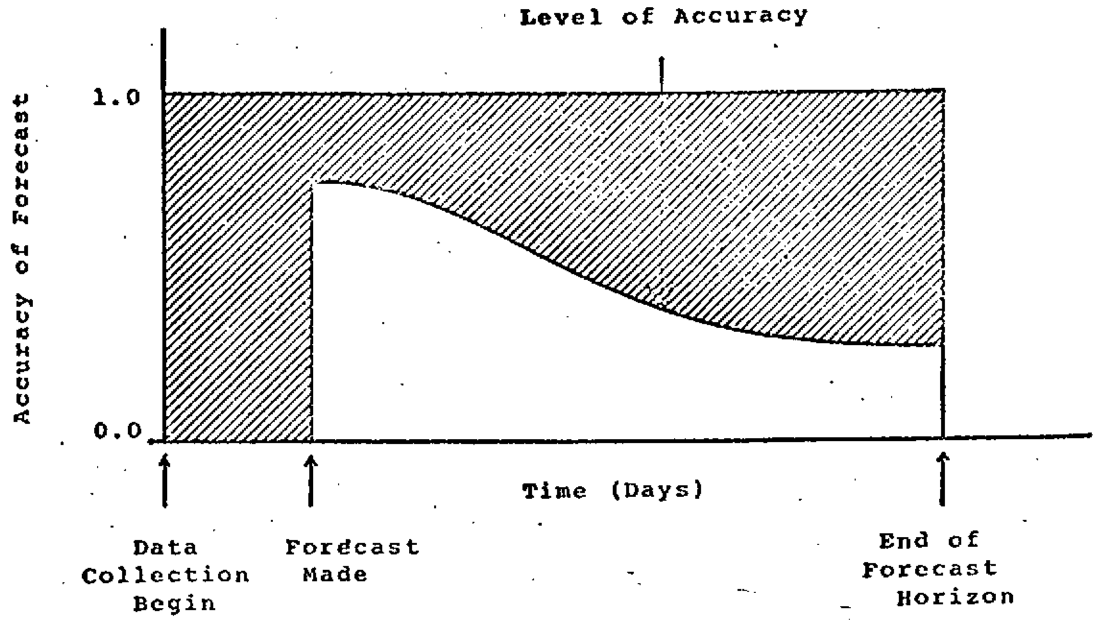


Figure 5.3 Forecast System Accuracy

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6.0 ECONOMICS OF MARINE EXPLORATION, EXTRACTION, AND DISTRIBUTION OF OIL

6.1 U.S. Supply and Demand for Oil

Explaining developments in the world petroleum market requires an elaborate analysis of the many physical, political, social, and economic factors involved. In this chapter, a background to the economics of the oil industry, with special reference to the U.S., is presented. As previously indicated, oil is the single most important product in world shipping accounting for more than half of all world trade. For this reason, use of SEASAT weather information for world shipping is intimately tied to the oil industry and an overview of the oil industry will be useful for understanding the analyses to follow. However, it should be kept in mind that the economics of the industry represents a limited point of view as the economic impact of a political action, such as the Arab embargo demonstrated.

There are numerous sources of information on the economics of the oil industry. These include: international organizations, such as the United Nations and the Organization for Economic Cooperation and Development (OECD) through its Oil Committee; the U.S. Federal Energy Office; numerous trade associations among which the more important in the U.S. are American Petroleum Institute in Washington and the National Petroleum Council in Washington; publications, exemplified by the Oil and Gas Journal and the International Petroleum Encyclopedia - both published by the Petroleum Publishing Company in Tulsa, Oklahoma - and the Petroleum Abstracts published by the University of Tulsa; and academic groups such as the Policy Study Group of the M.I.T. Energy Laboratory.

The production and consumption of energy in the economies of the world have been increasing and are expected to increase at a faster rate in the future. Table 6.1 illustrates the distribution of energy production and consumption for the U.S. versus the rest of the world. The figures for 1969 and 1972 show that the per capita consumption of energy by the U.S. is nearly six times the world average and nearly double that of a highly industrial country like West Germany, that a large energy producing area like the Middle East can be a low consumer of energy, and that dynamic changes in these patterns took place in the short span of three years. In the decade of the 1960's, global demand for energy expanded at an annual average rate of 4.9% and it is estimated that it will expand at a rate of 5.6% for the decade of the 1970's (see OECD [145, p.33]). Oil's share of the total energy sources increased from 33% in 1960 to 44% in 1970 and is expected to increase to 48% in 1980 (see OECD [145, p.33]).

Oil competes as an energy source with natural gas, coal, hydropower, and nuclear power. Geothermal power is

Table 6.1 Production and Consumption of Energy (in million metric tons of coal equivalent and in kilograms per capita)

	Production Total		Consumption Total		Consumption Per Capita	
	1969	1972	1969	1972	1969	1972
United States	1,952 (30.0%)	2,065 (27.3%)	2,186 (34.2%)	2,424 (35.5%)	10,784	11,611
West Germany	170 (2.6%)	171 (2.3%)	294 (4.6%)	332 (4.9%)	4,833	5,396
Middle East	829 (12.7%)	1,225 (16.2%)	68 (1.1%)	95 (1.4%)	661	857
Rest of World	3,561 (54.7%)	4,104 (54.2%)	3,849 (60.1%)	3,970 (58.2%)		
World Totals	6,512 (100.0%)	7,565 (100.0%)	6,397 (100.0%)	6,821 (100.0%)	1,808	1,984

Source: United Nations, Statistical Yearbook 1973, pp. 347-350.

expected to become a significant source of energy in the 1980's. Natural economic forces and political forces cause shifts in the composition of these energy sources. Table 6.2 gives forecasts of energy sources composition by the U.S. Department of Interior. These estimates were made before the Arab embargo

Table 6.2 Energy Input to the U. S. Economy, 1971, and Projections, 1975 to 2000 (in quadrillions of BTU's)

	1971	PROJECTIONS			
		1975	1980	1985	2000
Total gross energy input	69.0	80.3	96.0	116.6	191.9
By consuming sector:					
Net energy consumption	57.1	65.1	76.1	89.7	140.1
Non-fuel uses[1]	4.0	4.7	5.4	6.4	10.7
Percent of total	6	6	6	5	6
Residential and commercial	17.4	20.2	23.9	27.7	39.6
Percent of total	25	25	25	24	21
Industrial	22.6	25.9	29.4	34.9	57.8
Percent of total	33	32	31	30	30
Transportation	17.0	19.1	22.9	27.1	42.7
Percent of total	25	24	24	23	22
Conversion losses[2]	11.9	15.1	19.9	26.9	51.8
Percent of total	17	19	21	23	27
By energy source:					
Coal	12.6	13.8	16.1	21.5	31.4
Petroleum	30.5	35.1	42.2	50.7	71.4
Domestic supply	22.6	22.1	23.8	23.6	21.2
Supplemental supply	7.9	13.0	18.4	27.1	50.2
Percent of total	26	37	44	53	70
Natural gas	22.7	25.2	27.0	28.4	34.0
Domestic supply	21.8	22.6	23.0	22.5	22.9
Gas imports	.9	2.6	4.0	5.9	11.1
Percent of total gas	4	10	15	19	28
Nuclear power	.4	2.6	6.7	11.8	49.2
Hydropower	2.8	3.6	4.0	4.3	6.0

[1]Primarily asphalt and road oil in the residential and commercial sector, chemical feedstocks in the industrial sector, and lubes and greases in the transportation sector.
[2]Losses caused by converting a primary energy source to a secondary energy source.

Source: U.S. Dept. of the Interior, United States Energy Through the Year 2000.

[Reproduced from the Department of Commerce, Statistical Abstract of the U.S. 1973, p.508.]

on oil and estimates for petroleum were 43% of total energy sources expected in 1985 (50.7/116.6=43%). As Table 6.3 illustrates, the resulting large price rise for oil had a profound effect on expectations. The estimates by the Federal Energy Office (FEO), which were made after the Arab oil embargo, indicate that oil is expected to comprise only 31% of energy sources in 1985 (15.3/49.6=31%).

There are numerous economic studies which give insight into the economic aspects of changes in the energy sources composition. An example of such a study would be D.Schwartzman, "The Cost-Elasticity of Demand and Industry Boundaries: Coal, Oil, Gas, and Uranium", Antitrust Bulletin, 18(3), Fall, 1973, pp.483-507. Quarterly listings and selected reviews of articles on the extractive industries which appear in a wide variety of economic journals are given in Section 632 of the Journal of Economic Literature published by the American Economic Association.

Table 6.3 U.S. Supply and Demand for Energy, FEO

	All Figures in Millions of Barrels per Day of Oil Equivalent								
	1973	1974	1975	1976	1977	1978	1979	1980	1985
Oil	10.9	11.1	11.3	11.6	12.0	12.5	13.0	14.0	15.3
Shale	--	--	--	--	--	.1	.3	.5	1.5
Natural Gas	11.2	11.2	11.3	11.5	11.8	12.0	12.8	13.2	15.0
Coal	6.9	7.4	7.9	8.4	9.0	9.6	10.3	11.0	12.1
Hydro	1.4	1.4	1.4	1.4	1.4	1.5	1.5	1.5	1.6
Nuclear	.1	.2	.4	.4	.6	.8	.9	1.3	2.6
Geothermal	--	--	--	--	--	.1	.3	.6	1.0
Total Supply	30.5	31.3	32.3	33.3	34.8	36.6	39.1	42.1	49.6*
Demand @ 2 percent	36.6	37.3	38.0	38.8	39.6	40.4	41.2	42.1	46.5
Net Imports Needed	6.1	6.0	5.7	5.5	4.8	3.8	2.1	0	-3.1

Source: Saturday Review [45, p. 53].

A recent article which pulls together some of the economic modelling in this area is given in Policy Study Group of the M.I.T. Energy Laboratory, "Energy Self-Sufficiency: An Economic Evaluation", Technology Review, May, 1974. Many of the models are very complicated and start with the supply and demand for products which use energy and from an analysis of these markets derive the demand for oil. These studies are analytic in that they look at the structural variables (e.g., prices, incomes, population, employment, investment, etc.) in a consistent framework, i.e., a mathematical model. These studies may be contrasted to studies which use past data on oil demand to make forecasts without relating them to structural variables.

The analysis of supply and demand of various energy sources of the separate models is drawn together in the forecasts for 1980 given in Table 6.4. The non-analytic estimates of the National Petroleum Council (N.P.C.) are substituted in the lower box (judgmental supply). The analysis is done for three alternative prices for a barrel of oil in 1980 ($7.00, $9.00, and $11.00). The forecasts of demand of the Hudson-Jorgenson model are contrasted with judgmental demand estimates. The Hudson-Jorgenson model indicates a significant drop in demand if prices go up while the judgmental estimates assume the movement of prices will not affect the demand for oil. Short run elasticities (see Glossary) of demand for oil are approximately -.15, while long run elasticities are more likely in the range of -.20 to -.40 (see Technology Review [197, p.29 fn, and p.49]). The results in all but one case show that the supply will not exceed the demand or that the U.S. will not achieve energy self-sufficiency in these price ranges and will have to continue to import energy sources to make up the deficit.

Table 6.4 U.S. Supply and Demand for Energy, 1980, Under Alternative Oil Prices

Fuel	Source of estimate	Millions of barrels per day equivalent, at prices per barrel: $7.00	$9.00	$11.00
Crude oil	Erickson-Spann	8.4	10.4	12.4
Natural gas liquids	M.I.T. model	2.1	2.2	2.4
Natural gas	M.I.T. model	14.7	15.8	16.9
Coal	M.I.T. analysis	7.1	8.0	8.0
Uranium and hydroelectric	Equipment survey	6.2	6.2	6.2
New technology	M.I.T. analysis	0.0	0.0	0.1
Total supply		38.5	42.6	46.0
Forecasts of total demand	Hudson-Jorgenson	44.2	42.4	40.6
	Judgmental	45.6	45.6	45.6
Crude oil and natural gas liquids	N.P.C. (Case I)	13.6	13.6	13.6
(including Alaskan)		(2.0)	(2.0)	(2.0)
Natural gas	N.P.C. (Case II)	11.5	11.5	11.5
Coal	M.I.T. analysis	7.1	8.0	8.0
Uranium and hydroelectric	Equipment survey	6.2	6.2	6.2
New technology	M.I.T. analysis	0.0	0.0	0.1
Total supply		38.4	39.3	39.4
Forecast of total demand	Hudson-Jorgenson	44.2	42.4	40.6
	Judgmental	45.6	45.6	45.6

Source: Adelman [197, p.28]

The figures in Table 6.5 below indicate the distribution of energy sources among the sectors of the economy which is forecasted for 1980.

Approximately 60% of the oil will be consumed for transportation purposes.

Tables 6.6 and 6.7 give the world production and reserve levels for 1973 and an estimated productive capacity in 1980. There is some confusion as to known reserves. There is no consistent definition of "proved reserves". The estimates of reserves are gathered from trade journals and associations but in a non-rigorous method. The world average ratio of "proved reserves" to annual production is approximately 32:1, (see OECD [145, p.51]). The figures for proved reserves exclude oil in place but not exploitable currently, which is 70% of all oil in place. With better recovery technology, this

Table 6.5 U.S. Sources and Uses of Energy in 1980

Fuel	Residential and Commercial Sector	Industrial Sector	Transportation Sector	Electric Utilities	Total
Coal	150	6,500		10,200	16,850
Petroleum	6,800	6,000	22,000	2,520	37,320
Natural Gas	10,500	12,000	1,000	6,000	29,500
Electricity (Net)	6,000	3,600	20		
Nuclear				9,600	9,600
Hydroelectric				3,500	3,500
Total	23,450	28,100	23,020	31,820	96,800

Source: Adelman [197, p. 30]

Table 6.6 World Oil in 1973				
	Production		Reserves	
	million bbl./day	per cent	billion barrels	per cent
Western Hemisphere	16.1	28.9	76.1	13.4
United States	9.2	16.5	34.6	6.1
Venezuela	3.4	6.0	14.2	2.5
Canada	1.7	3.1	9.7	1.7
Others	1.8	3.3	17.6	3.1
Western Europe	0.4	0.7	15.9	2.8
Middle East	21.4	38.3	350.3	61.7
Saudi Arabia	7.7	13.8	140.8	24.8
Iran	5.9	10.5	60.2	10.6
Kuwait	3.1	5.6	72.7	12.8
Iraq	2.0	3.5	31.2	5.5
Others	2.7	4.8	45.4	8.0
Africa	5.8	10.5	67.6	11.9
Libya	2.2	3.9	25.6	4.5
Nigeria	2.0	3.6	19.9	3.5
Algeria	1.0	1.8	7.4	1.3
Others	0.6	1.1	14.7	2.6
Asia-Pacific	2.2	4.1	15.9	2.8
Indonesia	1.3	2.4	10.8	1.9
Others	0.9	1.7	5.1	0.9
Communist Countries	9.8	17.5	42.0	7.4
USSR	8.4	15.1	34.6	6.1
China	1.0	1.8	7.4	1.3
Others	0.4	0.7		
World Total	55.7	100	567.8	100
O.P.E.C. Members	30.8	55.3	416.3	73.3
A.O.P.E.C. Members	18.4	33.0	299.8	52.8

Source: Adelman [197, p. 48].

unexploitable oil may become exploitable. Improving the 30% recovery rate by 1% would mean the equivalent of one year's current production (see OECD [145, p.52]).

Table 6.7 Estimated Changes in World Oil Production, 1973-80

	Production in 1973, in millions of barrels per day	Estimated Productive Capacity in 1980, in millions of barrels per day
Non-O.P.E.C.	24.9	44.6
United States	9.2	10.4
North Sea	.0	6.4
Other Non-O.P.E.C.	15.7	27.6
O.P.E.C. "Expansionist" Nations	12.2	17.9
Algeria	1.0	1.1
Indonesia	1.3	2.0
Iraq	2.0	4.0
Iran	5.9	8.0
Nigeria	2.0	2.8
O.P.E.C. "Conservative" Nations	18.6	24.9
Venezuela	3.4	3.4
Kuwait	3.1	3.3
Libya	2.2	2.2
Other Persian Gulf	2.2	2.8
Saudi Arabia	7.7	13.2
World Total	55.7	87.4

Source: Adelman [197, p. 49]

The distribution of capital funds in world oil operations is given in Table 6.8. Offshore production is currently about 17% of the total world output, so that offshore production costs accounted for at least 7% (17% x 43%) of all expenditures during 1960-1969. As will subsequently be discussed, this is probably a conservative estimate, as the cost of producing a barrel of oil offshore is greater than the cost

Table 6.8 World Oil Capital Expenditures, 1960-70 Period (in millions of dollars)

	Production	Refineries	Marketing	Marine	Pipelines	Chemical Plants	Other	Total
United States:								
Dollars	44,435	6,720	10,300	640	3,340	5,360	2,680	73,475
Percent	60	9	14	1	5	7	4	100
Other World:*								
Dollars	22,610	17,710	14,325	14,750	4,515	5,805	2,110	81,825
Percent	28	22	17	18	6	7	2	100
Total:								
Dollars	67,045	24,430	24,625	15,390	7,855	11,165	4,790	155,300
Percent	43	16	16	10	5	7	3	100
1970 Total	7,230	4,000	3,220	2,615	850	1,525	685	20,125
1960 Total	5,610	1,130	1,425	1,110	550	460	240	10,525
Percent increase in annual expenditures over the period 1960 to 1970	29	254	126	136	55	231	185	91

*Excluding the USSR, other Eastern European countries and China.

Source: OECD [145, p. 158].

of producing a barrel of oil on land. Marine transportation absorbed 10% of all expenditures during the same decade. These two areas are the areas of principal concern of this study.

6.2 Derived Demand for Tankers

The demand for tankers is derived from the demand for oil which was discussed in the previous section. The forecasts of tanker needs are likewise derived from forecasts of oil demand and the technical developments in the size and performance characteristics of the worlds tanker fleet. The Sun Oil Company has been publishing an analysis of the world tanker fleet since the mid-1940's. The summary and conclusions for the year ending December 31, 1972, are listed in Section 6.3.

Tables 6.9, 6.10, and 6.11 indicate, respectively, the distribution of the world's tanker fleet by country, the

Table 6.9 World Tank Ship Fleet at December 31, 1972

Flag	Number of Vessels	Deadweight Tonnage
Liberia	906	58,896,500
United Kingdom	441	27,904,000
Japan	315	27,729,400
Norway	389	24,732,400
Greece	252	11,045,800
United States	328	9,253,300
France	125	8,666,400
Panama	190	7,321,300
Italy	153	6,832,100
U.S.S.R.	376	5,329,100
Sweden	76	5,090,600
Denmark	47	3,675,000
All Others	738	24,406,300
Total World	4,336	220,882,200

Source: Sun Oil Company [1,p.4].

Table 6.10 World Tank Ship Fleet

Dec. 31	Number of Vessels	Deadweight Tonnage
1962	3,259	71,996,000
1963	3,279	76,179,000
1964	3,359	85,126,000
1965	3,436	93,172,000
1966	3,524	102,909,000
1967	3,613	112,366,000
1968	3,775	128,128,000
1969	3,893	146,029,000
1970	4,002	167,940,000
1971	4,207	193,891,000
1972	4,336	220,882,000

Source: Sun Oil Company [1,p.3].

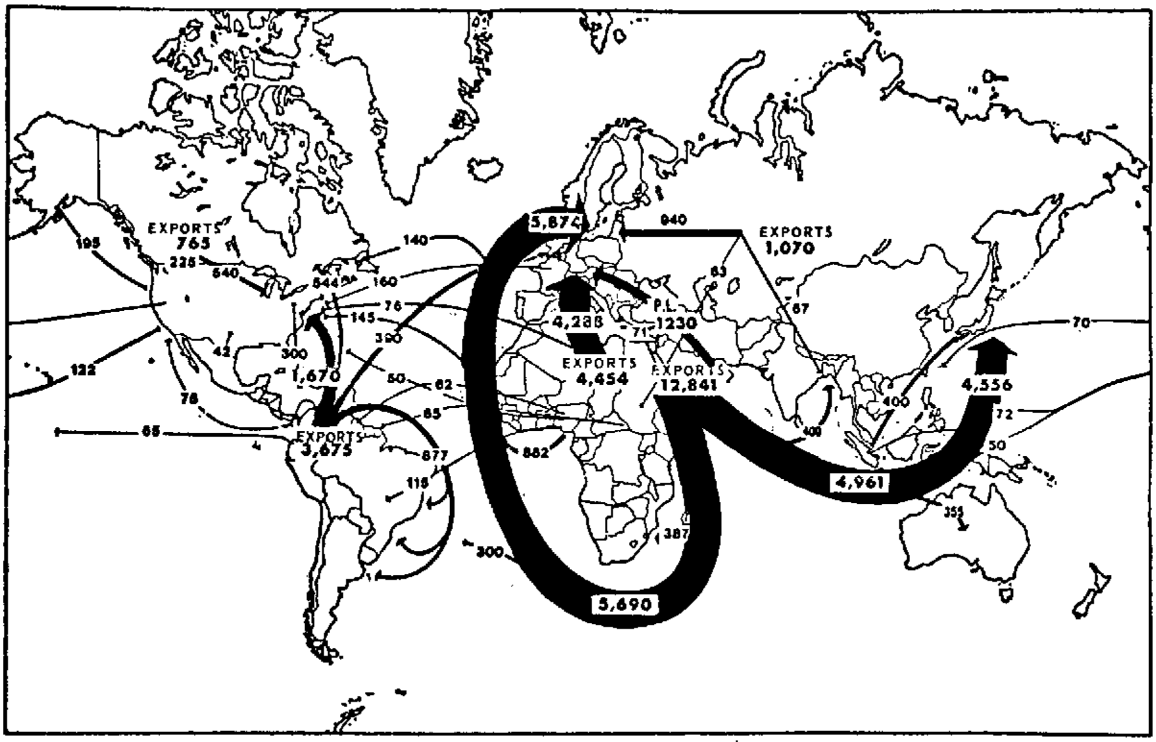
Table 6.11 Tank Ships Under Construction or on Order
December 31, 1972
(not including combined carriers)

Intended Flag of Registry	Number of Vessels	Deadweight Tonnage		
		Total	Average Per Vessel	Per Cent of Existing Fleet
Liberia	144	27,564,000	191,400	46.8%
Japan	96	18,196,000	189,500	65.6
Norway	82	14,203,000	173,200	57.4
United Kingdom	84	12,080,000	143,800	43.3
France	27	5,724,000	212,000	66.0
United States	41	3,332,000	81,300	36.0
Sweden	28	3,301,000	117,900	64.8
Denmark	14	3,174,000	226,700	86.4
Panama	21	3,153,000	150,200	43.1
Italy	25	2,546,000	101,800	37.3
Greece	23	2,140,000	93,100	19.4
Spain	14	2,072,000	148,000	59.8
West Germany	15	1,891,000	126,000	57.8
Brazil	11	1,239,000	112,600	124.1
U.S.S.R.	37	1,188,000	32,100	22.3
All Others	130	14,759,000	113,500	88.5
Total World	792	116,559,000	147,200	52.8

Source: Sun Oil Company [1,p.15].

growth in the world tanker fleet, and the growth in deadweight tonnage from 1962 to 1972, and tankers under construction or on order.

The principal trade flows in oil are to be found in OECD Marine Transport [12] and in various United Nations trade statistics publications, such as Commodity Trade Statistics, Series D. A world map illustrating the trade flows in 1970 is given in Figure 6.1. Tanker rates are quoted in worldscale (see glossary) figures. The behavior of these tanker rates in oil trade flows are presented in numerous sources. These are surveyed in Section 5.3, Freight Rate Economics. Costs of operating a 120,000 tanker are given in Section 5.1,



Source: OECD [145, p. 122].

Figure 6.1 Major World Oil Flows, 1970
(in thousand barrels per day)

Overview and Definition, of the Maritime Industry chapter. The future growth of the U.S. tanker fleet is directly tied to the operation of the Alaska oil marine link. The U.S. tanker fleet required here is discussed in Section 7.4.4, the Results, from the section on the Trans Alaska Pipeline.

6.3 Summary and Conclusions*

1. The world tank ship fleet on December 31, 1972, consisted of 4,336 vessels of 2,000 gross tons or more and totaled 220,882,000 deadweight tons. Compared with one year earlier, the fleet was 129 vessels larger and total deadweight tonnage increased 26,991,000 dwt or 13.9%.

* For 1972; reproduced from Sun Oil Company [1,pp.1 and 2].

2. The carrying capacity of the world tank ship fleet at the end of 1972 was equivalent to 14,320 T-2 tank ships, a gain of 1,743 T-2 equivalents of 13.9% from 1971. During the past ten years, the fleet has trebled, having grown at an average rate of 12.1% per annum.

3. During 1972, a total of 236 tankers equivalent to 1,850 T-2's were delivered into the fleet, while 110 vessels equal to 135 T-2's were scrapped. Transfers between flags amounted to 143 vessels or 332 T-2's.

4. Liberia remained the leading flag or registry in 1972, representing 26.7% of the world carrying capacity compared with 25.0% in 1971. In rank order, United Kingdom, Japan, Norway, and Greece occupied second, third, fourth, and fifth largest flag positions, respectively.

5. The average deadweight tonnage of ocean-going tank ships increased to 50,900 dwt at the end of 1972 from 46,100 dwt a year earlier. Average speed remained unchanged at 15.8 knots.

6. The average age of the world tank ship fleet was seven years, one month at the end of 1972, two months less than in 1971. During the past decade, the average age of the fleet has ranged narrowly between seven years, one month, and seven years nine months.

7. Japanese flag tankers remained the youngest among the principal flags of registry, averaging four years, three months at the end of 1972. U.S. flag tankers were the oldest, averaging 16 years, two months in 1972.

8. At the end of 1972, there were 792 tank ships representing 116,559,000 dwt under construction or on order in world shipyards. This was an increase from one year earlier of 19 vessels and 16,309,000 dwt. The average vessel under construction increased in size to 147,200 dwt from 129,700 dwt in the previous year. The amount of tonnage under construction

or on order in 1972 was seven times greater than ten years earlier.

9. The leading country of construction again in 1972 was Japan with 57,760,000 dwt or 49.5% of total world tonnage under construction in its shipyards at year-end.

10. There is a demonstrable need to provide deep water terminal facilities on the U.S. East, Gulf, and West Coasts in order to accommodate sharply rising requirements for waterborne oil during the next decade.

6.4 Offshore Oil Economics

6.4.1 Introduction

The current forceful growth in world-wide offshore oil operations is well-known. The economic reasons for the growth are not, however, perfectly understood. The motive forces seen by some* arise from the tremendous world-wide energy demand which seems to support total geographic prospecting, the associated need for the development of oil reserves, and taxation policies in various nations which seem to favor undersea exploration. Associated with these forces is a belief, however, that undersea oil operation will always be more expensive than land oil operations.

On the other hand, other oil authorities** suggest that the oil industry is being drawn, not pushed, into the sea by the well-founded expectation of lower costs. It has been observed that the unit finding cost is lower offshore because of better success ratios, larger fields, and easier drilling

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* Aspects Economiques de la Prospection et de l'Exploration des Hyrodarbures en Mer. Jean Masseron.

** Lewis G. Weeks, Offshore Development and Resources, Journal of Petroleum Technology, April 1969, pp. 377-85.

in softer sediment where "fifty or more development wells may be drilled from a single three to five million dollar platform".

It is also evident that, as onshore oil exploration in politically stable areas becomes less economically rewarding and dependency on Middle East oil becomes increasingly economically and politically hazardous, offshore oil development assumes significance to world-wide political and economic decisions. In subsequent discussion, the reasons for growth will not be investigated further. What will be outlined, of this complex subject, will be the economic influences on exploration, development, and production of offshore oil, the interrelated problems of offshore leasing and the trends in exploration and development technology. Exploration is the phase of operation where money is expended to find oil deposits. Development is the phase where the vertical and horizontal reservoir limits in a given field are determined. Production or well operations treat the production costs for a unit of oil produced.

It is customary, as a framework for economic discussion, to model an industry as an economic totality under four headings, viz

1. A Consumption Function,
2. A Production Function,
3. An Investment Function, and
4. The Cost of Supply.

Essentially, the discussion will consider these four functions but they will not necessarily be explicitly identified.

The offshore oil industry is itself part of the total oil industry and there is evidently economic coupling between offshore and terrestrial oil production.

The gas and oil industry supplies 75% of the world's total energy demand and almost all of the energy required for transportation. New petroleum deposits thus must be sought constantly to ensure a continued supply of this energy.

World offshore oil reserves are estimated to exceed 80 billion barrels, more than 14% of the world's total reserves of about 570 billion barrels. Current world offshore production is about 8 million bpd, or 17% of total world output (Figure 6.2).

Offshore gas and oil now is sought world-wide. Wells have been drilled in offshore waters of at least 70 countries, and production now comes from at least 25 countries. These offshore areas may provide up to 200 billion barrels of new oil reserves during the next 20 years. Ultimately, they may provide up to 700 billion barrels of oil.

From 1961-1971, the petroleum industry spent $180 billion to find, develop, transport, process, and market the world's reserves (Figure 6.3). Of this total, $77.7 billion was spent on production and exploration alone (excluding pipelines and gas plants).

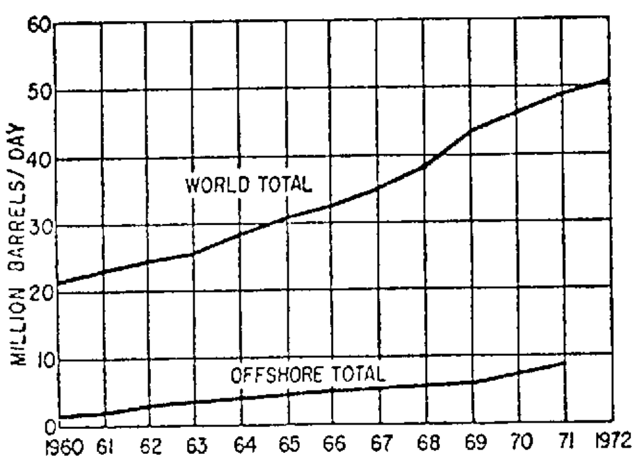

Figure 6.2 World Oil Production 1960-1971

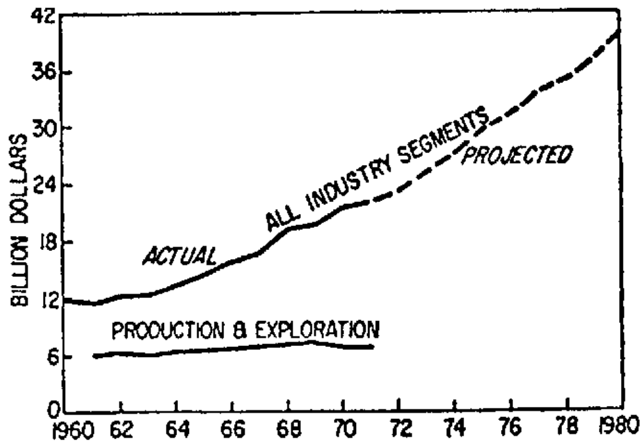

Figure 6.3 Capital and Exploration Expenditures -- World-Wide

To satisfy future world demand for oil, the industry will have to spend much more over the period 1970-1985 than it has over its past history. According to Chase Manhattan Bank, projected capital investment and exploration expense over this period will total $600 billion, $265 billion of which will be spent on exploration and production alone.

If predictions prove true, the offshore oil industry should experience a tremendous growth during that time.

All oil companies are now borrowing heavily to expand facilities and production to meet increasing world demand. The costly barrels of oil found today are worth no more than the cheaper barrels found over past years in today's markets. The governments of the world must recognize this and the higher costs to develop new oil reserves -- especially offshore.

6.4.2 General Offshore Oil Operations

The first drilling for offshore oil took place around 1900 when wells were drilled from beach piers in

California. Later, in the early 1930's, wells were drilled from timber platforms in the marshes of South Louisiana and along the coastlines.

The offshore oil industry of today probably had its beginning in 1947 when the first all-steel platform was placed in 20 feet of water in the Gulf of Mexico. Since then, well over 2,000 steel platforms have been installed and more than 15,000 offshore wells have been drilled in U.S. waters. Hundreds more platforms have been installed throughout the world and oil now is being produced offshore in more than 20 other countries.

Offshore activities are generally more challenging than those onshore. For instance, they cost more and new techniques have to be developed to solve unique problems. Since the mid-1950's offshore work has moved gradually into deeper waters. With today's technology, offshore wells can be drilled successfully in water depths to about 1,500 feet and production may be established from that depth soon.

However, costs continue to rise. Oil production cost trends since 1956 are shown in Figure 6.4. Figure 6.5 shows how the drilling cost trend compares with all oil production costs since 1956. As indicated, drilling costs are

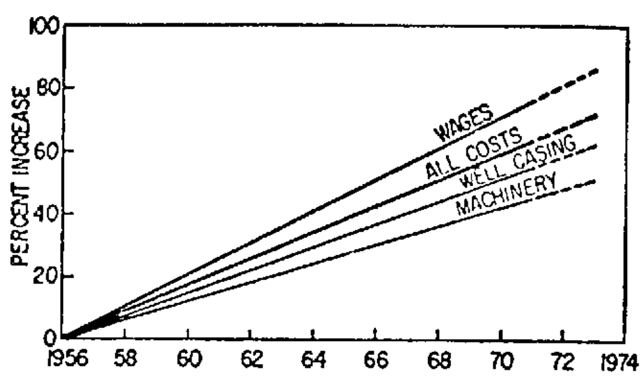

Figure 6.4 Oil Production Cost Trends

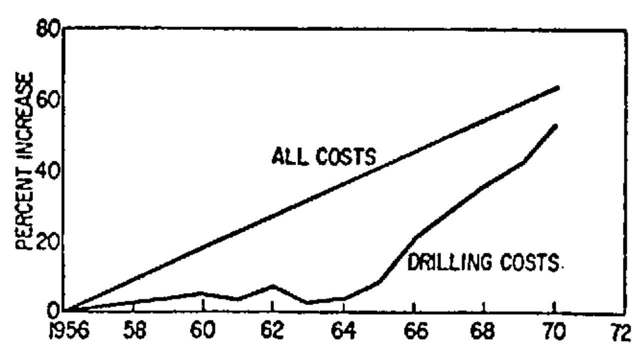

Figure 6.5 Drilling Cost Trends

increasing at a faster rate than other costs due partly to more use of complex equipment. Figure 6.6 shows a decline in the number of wells drilled -- especially in the United States. In areas outside the United States, the number of wells drilled per year has remained fairly constant.

Currently, some 400 offshore drilling rigs are operating world-wide and these will drill about 1,800 wells this year. Figure 6.7 shows the increase in the number of offshore drilling rigs since 1960 and the rising trend in the number of offshore wells. Construction of offshore rigs

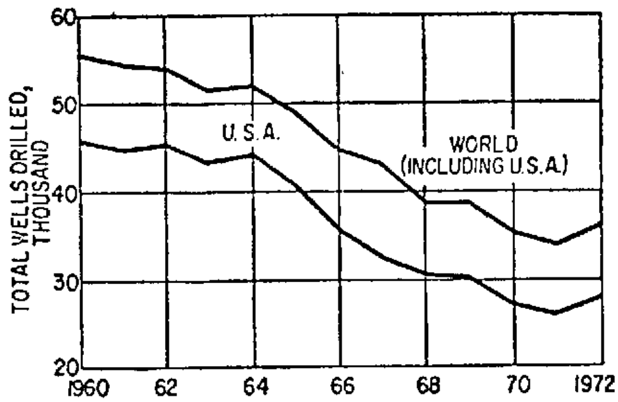

Figure 6.6 Drilling Activity

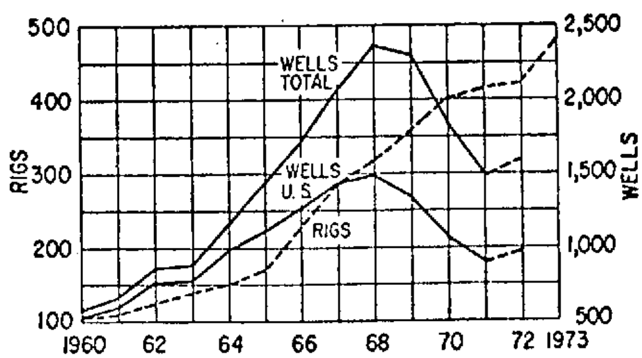

Figure 6.7 Offshore Rigs and Wells Drilled World-Wide

continues to grow. Recently, 81 drilling rigs costing about $1.25 billion were under construction world-wide. These include 54 semi-submersibles, 17 jackups, and 10 floaters (barge and ship-shape). These vessels are very costly and will add significantly to the overall cost of offshore drilling.

Offshore operations have been generally an extension of land techniques. Wells are drilled and completed from a platform; produced fluids are processed on the platform and transported to shore by pipeline. Well completion, maintenance, and workover operations are carried out by conventional means from the platform deck. Even offshore pipelaying is similar to a land operation.

This method of producing offshore oil has been successful, at least from an operating standpoint, in water depths to about 350 feet and structures are under construction for water depths of 400+ feet. All operations, whether from fixed platforms, jackup rigs, or floaters, are more expensive than land operations. In addition, overall problems of communication and logistics increase with distance from shore and, as the search moves to deeper water, cost continues to rise.

Figure 6.8 shows relative costs of offshore operations compared with those on land. In shallow water, costs

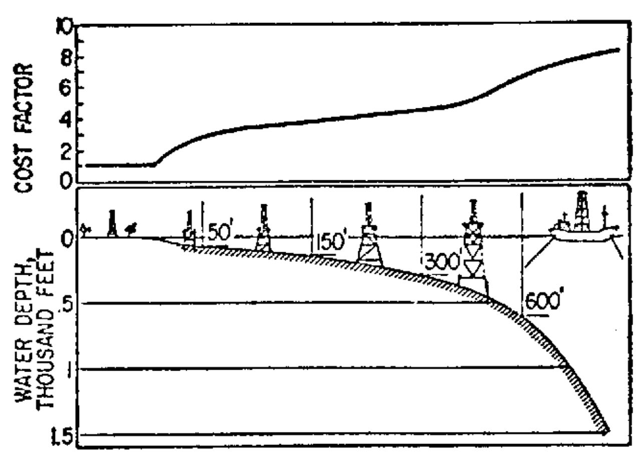

Figure 6.8 Costs Onshore and Offshore

are about double those of land operations, since paths must be dredged for drilling barges and flowlines and special foundations are needed to elevate wells and production facilities above water. In 100-300 feet of water, drilling wells from individual locations often is too expensive. Groups of 3-18 wells then are drilled directionally from one fixed support structure or platform.

Since fixed platforms have become more expensive with time and water depth, offshore costs have risen to three or four times those onshore. And, in water depths near 600 feet, cost of present-day platforms has risen to the level that overall operating costs may be about six times those on land. Beyond 600 feet of water, cost of fixed platforms is so high that drilling probably will be done from floating vessels, except in certain unique situations, such as in the Santa Barbara Channel where oil fields are located in deep water close to shore.

Figure 6.9 shows how average capital cost of offshore drilling rigs has increased. During the 1950's, when offshore drilling was done in marshes and shallow water bays, relatively low cost drilling vessels were used. As offshore work expanded into deeper water during the 1960's, drilling rig

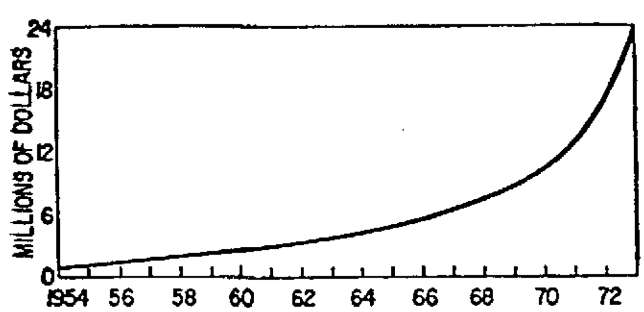

Figure 6.9 Offshore Drilling Rigs Typical Capital Cost

capital cost steadily increased. This was because the distance from shore increased with water depth and vessels used were exposed to more severe sea conditions. Vessels also became more sophisticated, had increased capabilities, and had to be self-contained and less dependent on shore based services craft for supplies.

During the past ten years, capital costs for drilling rigs have accelerated. Not only has cost of labor and materials increased, but expanded operations now require rigs capable of working world-wide in deep water. Requirements for anchoring, stability, mobility, and efficiency, to name a few, caused new types and much larger drilling vessels to evolve, such as the deep water jackup and semi-submersible.

An example of cost increase is that a semi-submersible vessel capable of sustained operations in the Gulf of Mexico cost about $9 million in 1967. A similar type drilling rig capable of sustained operations offshore in the North Sea costs about $30 million today. The capital cost trend for offshore rigs is upward and promises to continue as more complex, safe, and reliable vessels are built. For example, rigs costing to $45 million each now are on the drawing board.

A few oil companies build or operate some of their drilling rigs today. Although drilling contractors usually have the rigs built and provide a drilling service to the companies, costs are ultimately borne by the oil companies, since any increase in capital cost for a rig is reflected in the rate the contractor charges to do work.

Figure 6.10 shows probable range of daily rate for offshore drilling rigs as a function of their capital cost. Included are all types of vessels, from barges used in shallow water to large drill ships and semi-submersibles used in the open sea. Daily rate is essentially a direct function of rig

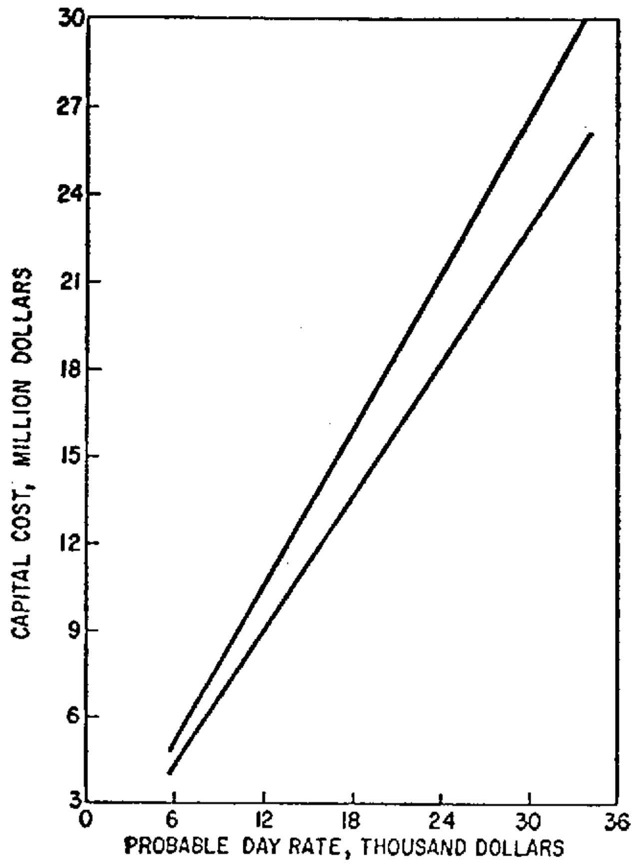

Figure 6.10 Offshore Drilling Rigs Probable Day Rate vs Capital Cost

capital cost and ranges from $6,000 to $36,000 as capital cost increases from $4 million to $30 million.

This cost relationship is expected to continue. Daily costs may actually increase at a greater rate than capital costs for these vessels because contractors must provide more complex equipment using special high grade steel and better trained personnel to meet demands imposed by more severe sea conditions in various parts of the world.

Water depth capability and daily rates for various offshore rigs are shown in Figure 6.11. In calm water to about 100 feet deep, submersible barges can be used at a relatively

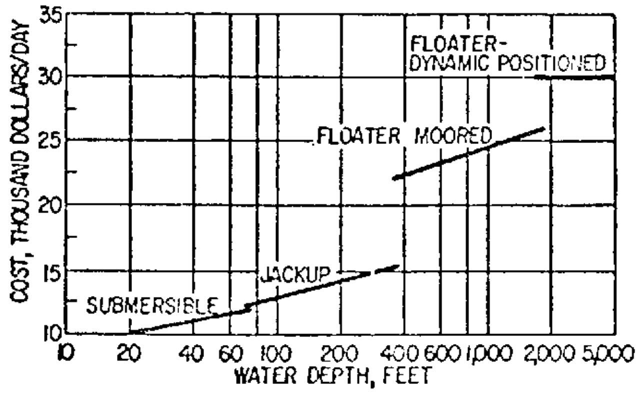

Figure 6.11 Daily Drilling Rig Cost vs Water Depth

low daily rate. In depths to about 400 feet, a variety of vessel types can be used. Choice in deep water depends on many factors, including geographic well location, rig availability, sea conditions, sea floor conditions, and whether drilling is exploratory or development. A self-contained platform is planned for about 750 feet of water in the Santa Barbara Channel and another for about 450 feet of water in the North Sea.

In water depths greater than 300 feet, floating rigs of various types are available for exploratory drilling. As water depths for floaters increase, amount of anchor chain or wire rope also increases and results in a corresponding increase in daily rate. In extreme water depths of 1,500 feet or more, automated thrusters are required instead of, or along with, conventional anchoring systems to keep vessels on location. Vessels with computer controlled dynamic positioning will help solve station-keeping problems. But cost of this added capability is reflected in daily rate which is the highest for any type of offshore rig.

Although offshore rig daily operating is a large part of the cost of drilling an exploratory well, it is by no means total cost.

Included are costs for mobilization and demobilization, towing, rigging up and down, tangible equipment items, interim mobilization, well logging, and operating. Mobilization and demobilization alone represent about 22% of the total cost of drilling an exploratory well. Mobilization and demobilization consist of preparing the drilling vessel for work. This includes rig time while enroute to and from a location, plus all of those intangible items required for drilling a well at a remote location such as drilling tools, mud supplies, fuel, water, food, etc.

Operating costs are only some 65% of the total costs incurred in drilling an offshore exploratory well. Cost figures for drilling in other areas in the world show a similar breakdown, but relative values change depending on geographical location, well depth, lithology, etc.

Generally, total drilling costs will range from $24,000 to $33,000 per day in mild weather areas when using small rigs. With large jackup and floating rigs, cost may increase to $40,000 per day in the same areas. These costs may range from $50,000 to $60,000 per day in severe weather locations, such as in the North Sea, using the new generation of drilling rigs. In ice-infested waters, total costs are expected to be $80,000 or more per day.

6.4.3 Offshore Oil Field Development

6.4.3.1 Introduction

Once an offshore oil field has been discovered and partially defined by exploratory drilling, a large investment is necessary for development operations needed for production. Normal development procedure is to first strategically locate necessary sea floor-supported drilling platforms and then drill directional wells and complete them at platform deck levels.

One or more platforms to support oil production equipment are installed nearby and sea floor flowlines are laid from drilling platforms to production platforms. Processed oil then may be pumped through sea floor pipelines to storage facilities located either onshore or on site. Stored oil may be later transferred to tankers via another sea floor pipeline leading to offshore tanker berths.

This is a very brief and general description of how an offshore field may be developed, but provides a background as cost of each major production item is examined in more detail.

6.4.3.2 Drilling and Completion

These costs vary from well to well for many reasons. Most importantly, depth and whether a well is drilled on land or offshore affect cost. For example, Figure 6.12 shows average costs for wells drilled to various depths, both onshore and offshore, in the United States during 1970. The curves indicate that wells drilled and completed offshore always cost about 1-1/2 to 2 times as much as their counterparts onshore. They also show that drilling and completion costs increase rapidly with well depth.

Figure 6.13 indicates how world-wide drilling and completion costs are expected to vary with increasing water depth. Costs taken from this curve should be doubled to determine the overall expense of placing a well in production. The additional cost will be for producing equipment, loading facilities, fluid handling, etc. If operations are in an area subject to extremely severe weather conditions -- such as the North Sea -- costs from the curve should be quadrupled to determine expense of establishing producing capability.

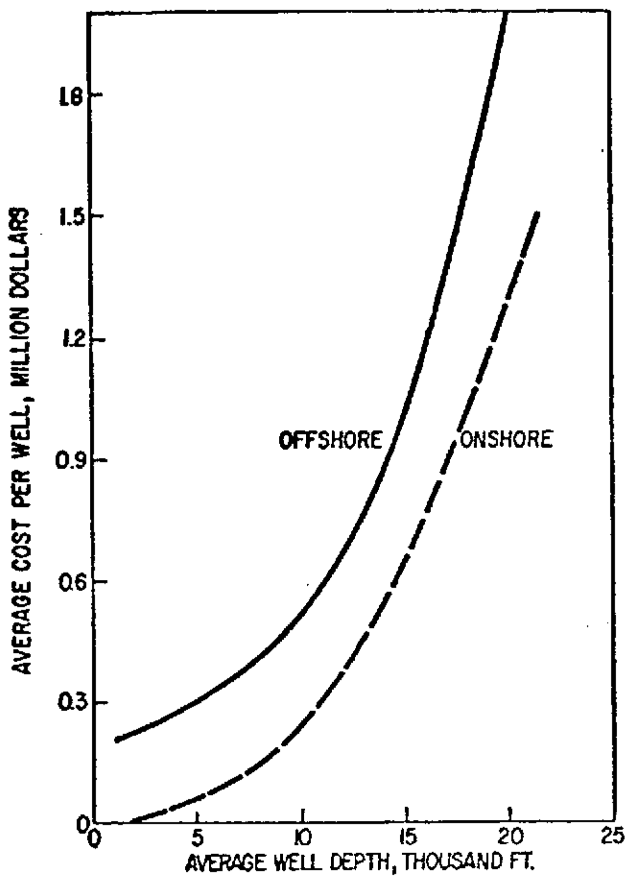

Figure 6.12 Drilling and Well Completion Costs U.S.A.

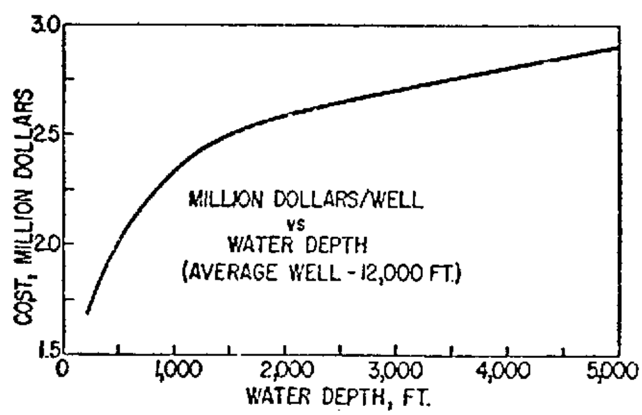

Figure 6.13 Estimated World-Wide Offshore Drilling and Completion Costs Per Well

6.4.3.3 Platform Installations

As mentioned earlier, development drilling platforms are strategically placed on the sea floor. Correct placement of these platforms not only optimize the number of wells to be drilled, but minimizes the number of costly platforms needed.

An offshore platform usually is composed of two parts: a rectangularly-shaped tubular steel jacket with four or more hollow legs and a shorter but similar steel deck. These steel frameworks are fabricated on land, then loaded on barges and towed to the drill site. The jacket section is placed upright on the sea floor using a construction barge. Heavy steel pipes are inserted into each jacket leg and driven deep into the sea floor to keep the jacket in place. After piles are welded at the top of the jacket legs, the deck section is placed on top of the jacket and welded to it.

Estimated cost of offshore platforms versus water depth is shown in Figure 6.14. These are average costs for platforms installed world-wide, but do not include cost of drilling or producing equipment. It can be seen that platform costs increase rapidly with increasing water depths. Of course, cost of any particular platform depends on a number of factors that will cause it to deviate from this curve. Some of these factors are: where it is built, sea conditions, sea floor load bearing capacity, and what it is designed to support. For example, platforms used in the North Sea may cost much more than would be indicated from Figure 6.14, while platforms built and installed in calm water areas may cost less.

Platform costs have continually increased over the past decade. Increases can be illustrated by showing how costs have risen for each component of a Gulf of Mexico platform.

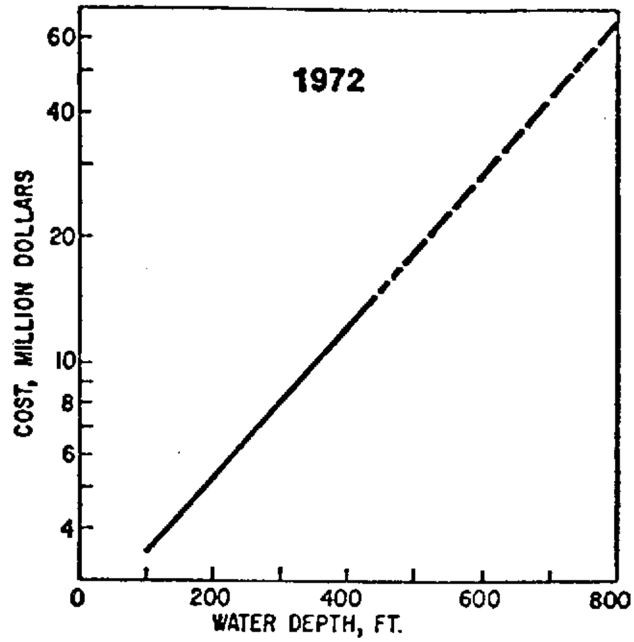

Figure 6.14 Estimated Offshore Platform Costs

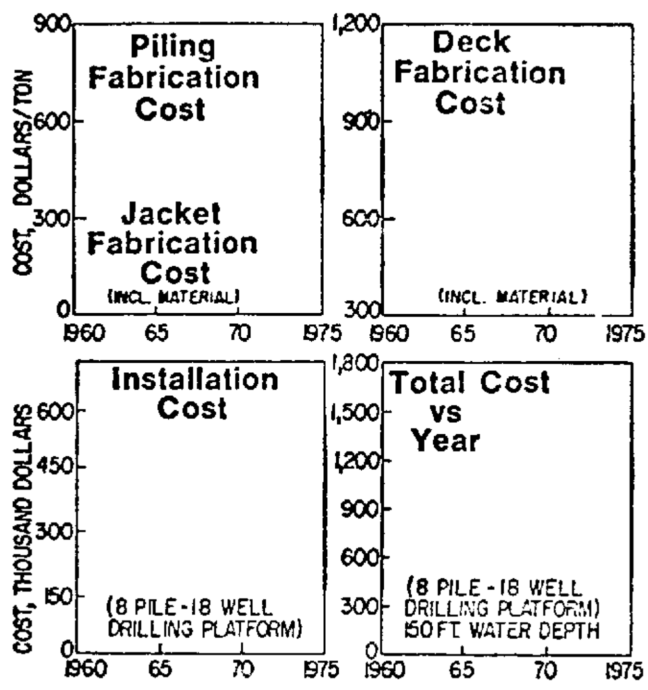

Figure 6.15 Piling and Deck Fabrication Cost, Installation Cost, and Total Cost vs Year

Figure 6.15 shows how costs have increased -- and still are rising -- for various components of platforms built for the Gulf of Mexico between 1960 and 1972. As indicated in the figures,

- Cost per ton for deck fabrication has increased from about \$750 to \$1,020
- Cost per ton related to jacket fabrication has risen from \$495 to \$840
- Cost per ton for piling fabrication is up 25% over the 12-year period
- Installation cost for an example 8-pile 18-well platform has more than doubled
- Total installed cost for an 8-pile 18-well drilling platform installed in 150 feet of water has about doubled

Figure 6.16 relates the range of total installed cost for a typical 8-pile 18-well drilling platform in 1972 to water depth. As indicated, cost increases rapidly as waters get deeper.

It should be emphasized that values shown in Figure 6.16 pertain only to Gulf of Mexico installation and, hence, vary from those shown earlier in Figure 6.14 which were average costs for various types of platforms installed worldwide.

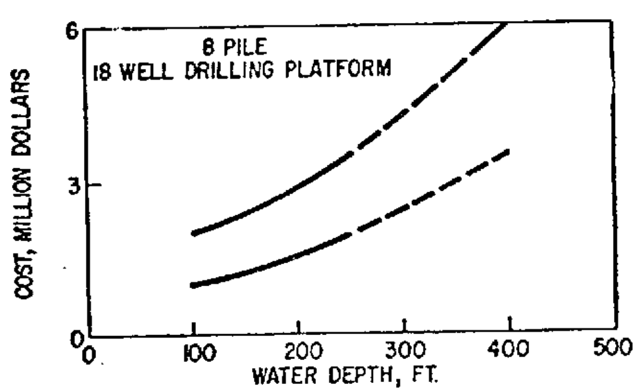

Figure 6.16 1972 Total Installed Cost

6.4.3.4 Producing Equipment

Representative 1972 costs for major items of gas and oil producing equipment are given in the accompanying table.

Prod. Rate	Separators	Treaters	Lact	Total
5,000 bpd	$ 70,000	$ 58,000	$25,000	$153,000
10,000 bpd	100,000	82,000	45,000	227,000
60,000 bpd	126,700	120,000	60,000	307,000

These costs represent a sizeable addition to expense of offshore oil field development and become especially significant when several installations are required in an oil field, not only as a capital investment, but as a continuing operating cost. Figure 6.17 shows average operating costs and how they are expected to vary with water depth.

6.4.3.5 Transportation and Storage

Cost of pipeline construction increases as water depth increases (Figure 6.18). There is a combination of water depth and distance to shore where pipeline costs become prohibitive. Then, some other means of transporting the oil must be considered; for example, on-site storage and tanker loading berth.

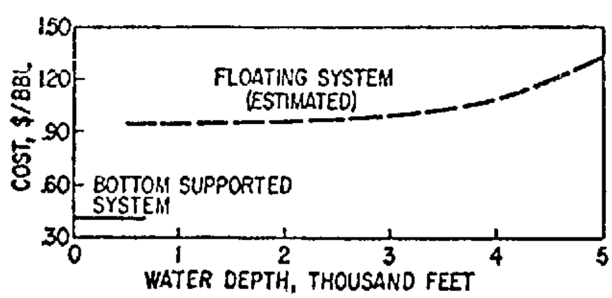

Figure 6.17 Offshore Operating Costs $/bbl vs Water Depth

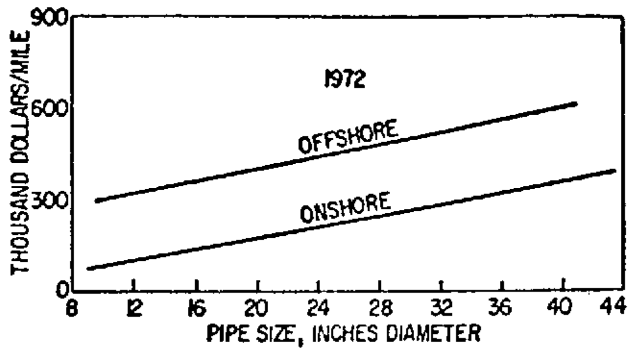

Figure 6.18 Average Pipeline Lay Costs

Floating offshore storage facilities are used successfully in some areas of the world. Several major floating storage vessels with a combined capacity of about 3 million barrels now are in service. Recently, a $15-million contract was awarded for construction of a 1-million barrel floating storage barge for use in Southeast Asia. Most floating storage vessels are used in relatively calm water in depths up to 160 feet. However, tankers are currently being used as temporary floating storage in deeper and rougher waters of the North Sea.

Installation of three 500,000-barrel underwater storage tanks in 150 feet of water in the Persian Gulf has demonstrated feasibility of this approach for on-site storage. More recently, a 1-million-barrel concrete sea floor storage unit was constructed for use in 250 feet of water in the North Sea. However, technical problems lie ahead in design and installation of underwater storage for deeper water and in methods for off-loading the oil to tankers.

As expected, when compared to conventional land storage tanks, offshore storage is expensive (Figure 6.19). Typically, differences in cost of various kinds of offshore storage, as compared to land storage, are as follows.

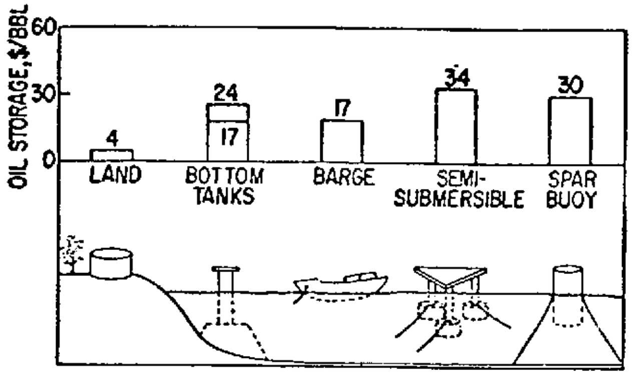

Figure 6.19 Comparable Oil Storage Costs

Type Storage	Cost Multiplying Factor
Land	1
Bottom tanks	3.5-5
Floating	
Barge	3-4
Spar buoy	6-7
Semi-submersible	3.5-5

For floating or sea floor types of on-site storage, some means must be provided for off-loading oil to transport vessels. An acceptable offshore tanker loading method uses a permanently anchored buoy (or series of buoys) for mooring the tanker near storage facilities. A submarine pipeline delivers oil from storage facilities, through the buoy, to the moored tanker. Single point bow mooring permits the tanker to weather vane as directed by wind and waves. This tanker loading method is finding widespread use as a means for transferring liquid cargoes offshore.

Cost of a typical installation varies from $1.5-$6 million, depending on oceanographic conditions, weather conditions, water depth, tanker size, etc.

6.4.4 Offshore Oil Economics

In performing an economic analysis of an offshore venture, a variety of producing situations are considered in an attempt to estimate the minimum amount of oil required to economically justify the investment for the proposed production facilities.

First, basic costs are estimated for development drilling and oil producing and handling facilities to be located offshore. These costs then are used to perform an economic study using a sensitivity analysis approach. In this method, various parameters are combined to determine a payout and discounted cash flow rate of return for various investment cases. The following items are usually used in this kind of study.

1. Finding costs - acquisition, geophysical, geological, and exploratory drilling expense
2. Development costs - development drilling, storage and oil producing, and handling facility costs
3. Direct operating expenses - production and administrative
4. Oil price
5. Royalty
6. Taxes - income and local
7. Depreciation
8. Oil producing rates

Various values for these items then are developed for a given project and, using a discounted cash flow calculation, interaction of the many variables is determined. Results of typical computations for a hypothetical offshore installation are shown graphically in Figure 6.20.

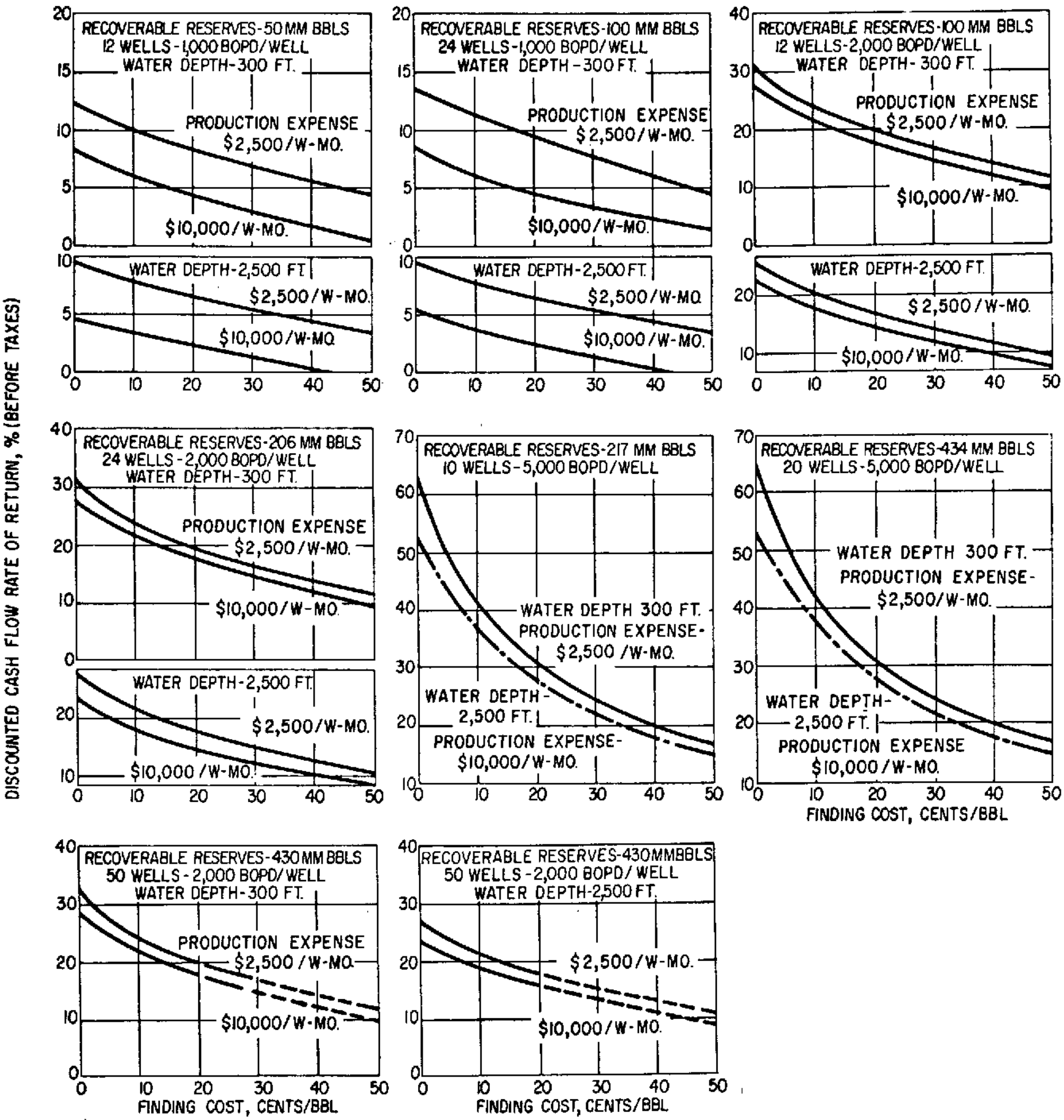

Figure 6.20 Economics of Offshore Development

These plots show that rate of return on monies invested in offshore development is (1) most sensitive to producing rate and, consequently, to size of the oil pool; (2) extremely sensitive to finding costs for a given producing rate; and (3) relatively insensitive to production expenses, except at the lowest producing rate.

Figures 6.21 and 6.22 graphically show rate of return versus recoverable oil reserves for two cases of a hypothetical installation in 300 feet of water. Parameters varied in these examples are number of wells, producing rate, production expense, and finding cost. Figure 6.21 indicates no return on monies invested for a 12-well installation when (a) oil reserves are less than 30 million barrels; (b) operating expense is $2,500 per well-month; and (c) there is no finding cost.

At the other expense extreme for this study (Figure 6.22), return is zero when (a) oil reserves are less than 50 million barrels; (b) operating expense is $10,000 per well-month; and (c) finding cost is 50 cents per barrel of oil. In water depths greater than 300 feet, oil reserves would have to be larger than 50 million barrels to have the same rate of return at an equal operating expense.

Figure 6.23 is a plot of payout time versus daily production rate for a field producing at rates up to 6,000 bpd per well. This curve was derived using average offshore well development costs and operating costs.

The curve indicates that, as production rate of a well is reduced from 5,000 bpd to about 1,000 bpd, field payout time more than doubles. This results from a high cost of working offshore and the time span over which offshore development takes place.

Therefore, higher capacity wells must be found if profitable operations are to be attained as operations progress into deeper water.

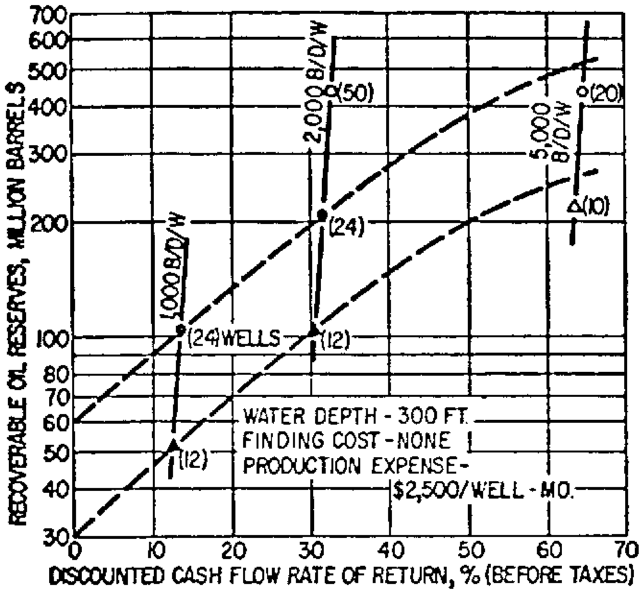

Figure 6.21 Economics of Offshore Development

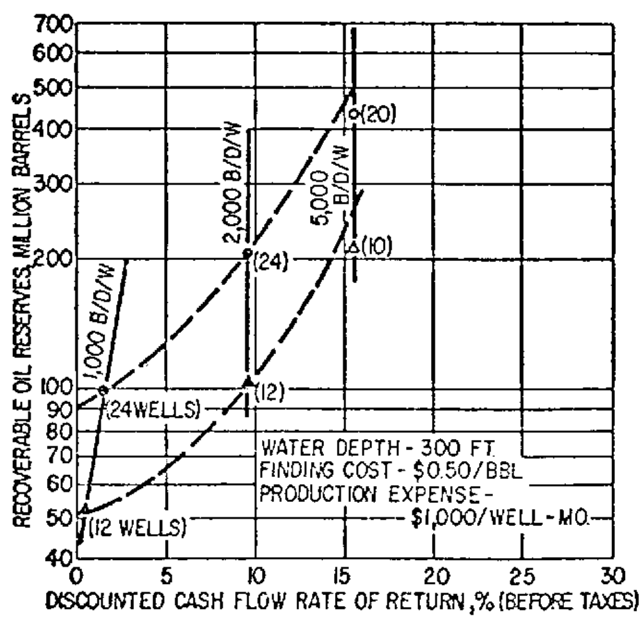

Figure 6.22 Economics of Offshore Development

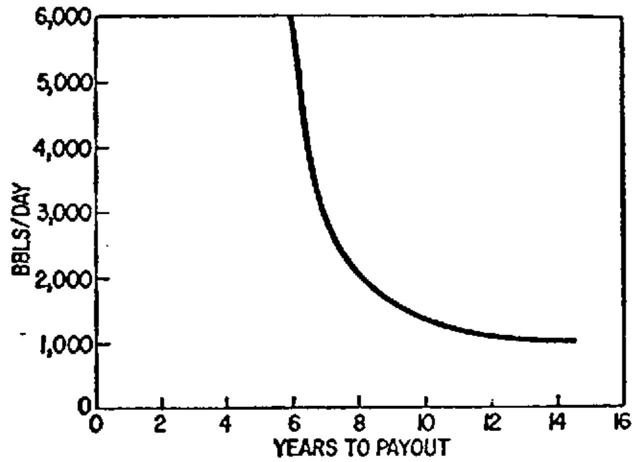

Figure 6.23 Field Development Well Production Rate vs Field Payout

6.4.5 Offshore Oil Technology

In recent years, many ideas and system concepts for deep water oil production have been proposed, some by companies outside the oil industry.

Drilling in water up to 20,000 feet deep, with penetrations into the bottom of up to 3,334 feet, has been achieved in the National Science Foundation Deep Sea Drilling Project. These operations were carried out from the Glomar Challenger, a dynamically positioned ship-shape drilling vessel. Using this same vessel, a drill hole was re-entered from the ocean surface in 13,000 feet of water.

More self-positioning drill ships are now under construction. These vessels incorporate design features that will enable contractors to drill at sea in practically unlimited water depths.

6.4.5.1 Underwater Well Completions

Now 10 or more years old, these completions can be extended to about any water depth in which a well is drilled.

Advances in underwater well completion and operating technology are reflected in the number of such wells that have been completed in the Gulf of Mexico. About 15 such wells now are in operation, testing various methods of valve control and through-the-flow-line work-over techniques. These wells, in water depths to about 375 feet, flow to, and are controlled from, platforms up to 6,000 feet away.

More recently, four 10,000 bpd wells were completed on the sea floor in the North Sea, three using National Supply Christmas trees and one using a Vetco tree. Three other highly productive wells were completed on the sea floor in the Persian Gulf using Deep Oil Technology Christmas trees. Currently, Gulf is testing a new type Cameron sub-sea tree on an onshore Louisiana well (Figure 6.24). This tree uses well pressure to actuate master valves, eliminating control lines to the valves.

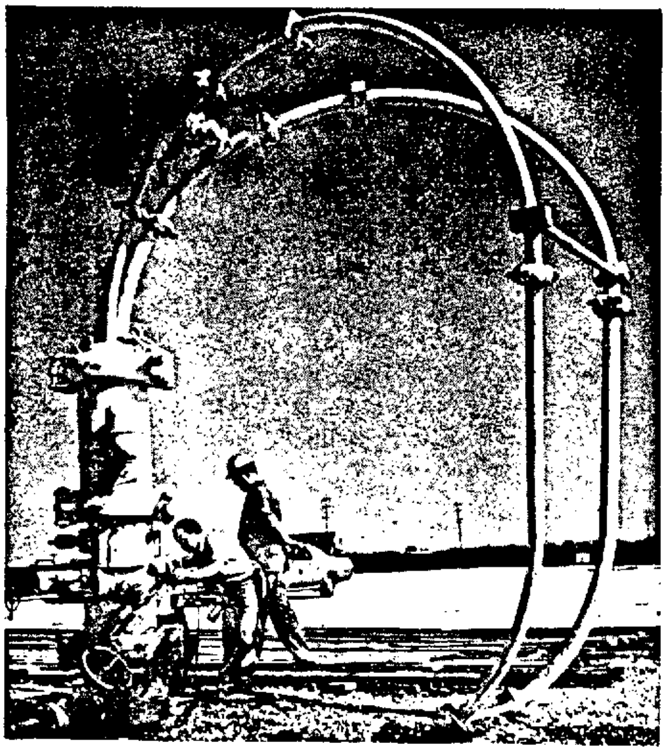

Figure 6.24 Land testing new type subsea tree

6.4.5.2 Deep Water Systems

Many new ideas and concepts for deep water oil production have been developed. Systems range from modular-type sea floor templates designed to support underwater well head components, with surface production and surface storage facilities, to complete underwater oil fields serviced by diving bells and/or submarines. As a result of some form of oil industry support, major components from several of the more promising concepts are being, or will soon be, tested.

For example,

- A two-year test program recently completed in the Persian Gulf evaluated all types of underwater equipment including well heads, flexible flow lines, wire line units, gas/oil separators, flare systems, and radio-isotope generator for sub-sea power.
- Lockheed Petroleum Services Ltd. has installed an encapsulated sub-sea well head, which men can visit in the "dry", on an oil producer in 375-foot-deep Gulf of Mexico waters.
- Sub-sea Equipment Associates, Ltd. (SEAL) also has installed a sub-sea production system in the Gulf of Mexico, but not on a "live" oil well.
- SEAL will install another less elaborate sea floor well head system with atmospheric environmental capability in the North Sea during 1974.
- An experimental prototype articulated platform, Elfocean, in continuous service from 1968 to 1972 in 328 feet of water in the Bay of Biscay, was recently removed for evaluation of operating components.

Pending settlement of environmental questions, industry's first production of oil from offshore locations in water 700-1,500 feet deep may take place in the Santa Barbara Channel, California. Methods and equipment have been designed and components have been built. The system uses proven oil field equipment, experience and technology, and is basically an extension of current offshore methods. The first platform to be installed will be 775 feet high and weigh about 20,000 tons. Design is underway on a similar structure for 1,000 feet of water.

Costs for each phase of offshore operations, from exploratory drilling through off-loading of oil to tankers, show that the cost of oil operations offshore are higher than similar land operations. Cost differentials between offshore and land operations are summarized in Table 6.12.

It is expected that these cost multiplying factors will increase in the future, particularly as operations extend into deeper water and into remote areas where environmental conditions are more severe.

Table 6.12 Variation of Cost with Water Depth

Cost Component	Cost Multiplying Factor (land=1)		
	100 feet	600 feet	1,000 feet
Exploration drilling	2	2.5-4.0	4.0
Development drilling	2	4.0-5.0	5.0-8.0
Production facilities	2	2.0-3.0	6.0-16.0
Pipelines	2	2.0-4.0	4.0-6.0

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7.0 MARINE TRANSPORTATION ROUTING

7.1 Optimum Ship Routing

7.1.1 Introduction and Survey of Case Study Results

7.1.1.1 Introduction

Currently most ship routing decisions are made just prior to departure. Transit time minimization is the prime criteria in selecting a route, along with the safety of crew and cargo. These criteria result in selecting great circle routes except for course deviations required to avoid bad weather conditions. Long-range (3 to 5 days) maritime weather forecasts are used to predict likely areas of bad weather.

After leaving port, ships continue to monitor weather reports from marine weather stations and ships at sea. They maintain weather charts, based on the monitored reports, which are used to make routing decisions. The amount of course correction that can be made is limited by the ship's speed. Typically this is in the range of 15 to 25 knots, with some container ships now being capable of 33 to 35 knots. The response to bad weather is generally to slow down and wait it out. Only for severe storms such as hurricanes or typhoons are abrupt course deviations made.

There are several commercial businesses which sell routing services to shipping companies. They provide both predeparture planning and post departure updates. The post departure updates are broadcasted in coded form and received and decoded by the ships of subscribing companies. MARAD personnel indicate that studies have been made which compared ships using a routing service with those not using such a service. The results of the studies show that the routing service did provide a net reduction in transit time overall, but not necessarily for every transit.

The military operate both East coast and West coast installations which route military ships and they use quite advanced techniques, successfully.

Minimization of the ship crossing time or transit time can then be translated into a reduced cost for operating the ship during the transit. The cost savings thus accrued are then one basis of benefit to the ship operatives. Whether the full cost saving can be realized by the shipping operation depends on full integration into the operation of the transit time reduction. That is the procedures required to berth the ship, unload and load cargo must allow the time saving to be realized.

Because transit time reduction is achieved by reducing the interaction between the ship and inclement weather conditions, if transit time reduction is possible then the insurance costs for insuring the ship and its cargo should also be reducible. Insurance costs reduction can be direct. That is, the actual marine underwriting may reduce the premium cost. Or the insurance reduction can be indirect. That is the ship operatives choose, because of SEASAT's capabilities, to increase the ship deductible and therefore self insure for more. This should reduce the actual transit insurance cost.

The insurance cost reduction, however achieved, is a second potential basis of benefit, to shipping, additional to that of reduced transit time.

For the particular transit considered in the case study (across the North Pacific) a cost saving can be associated with a capability to more precisely distinguish the transition, in terms of weather, and sea state between winter and summer. Such knowledge allows an earlier use of the time saving northerly routes and allows also cargo to be transported on ship decks.

The case study to be discussed investigated the potential dollar savings that could evolve from the application of SEASAT data to routing. The voyages considered were between

U.S. west coast ports and the Far East for containerized freight, and from the Persian Gulf to various international ports for oil tankers. The results of the case study indicated that the transit time saving for the freighters was about 2-5% of the transit time. For the Tankers, the results were not uniform.

Accumulated insurance savings were estimated. The magnitude of these cost savings is very difficult to determine precisely. Some of this difficulty arises in the process of marine underwriting which is not a science but an art. The insurance costs are based on the individual insurance experience of the underwriter and he may consider the ocean conditions and the weather to be a minor factor, compared to the ship's master and the ports at either end of the particular route.

Weather transition cost savings were not developed in this case study.

Generalization of this case study is a procedure which expands the case study findings to routes other than those of the case study. This required determination, as a projection, of the expected amounts of shipping world-wide in the future, based on the growth of the import-export trade, for the United States and ten trading partners. Further generalization for global trade (for example, between Europe and Asia, or South America and Asia) was not performed.

7.1.1.2 <u>Case Study Results</u>

7.1.1.2.1 <u>Ship Routing Results</u>

Ship routing optimization results were determined using the computing procedures of Ocean Routes Inc. Their computational procedure is as follows:

> Five routes for each voyage are selected. The route actually recommended to the ship will be within the area bound by the two outside routes. The routes are the same between ports, such as Yokohama and San Fracisco.

Imaginary vessels, with the same speed-in-a-calm (S_c) and identical performance characteristics as the routed ship, depart on comparison tracks at the same time as the routed ship leaves port on the recommended route. The speed-in-a-calm is the speed of the ship with no effect from weather or seas. Daily weather encountered by the imaginary ships on the comparison tracks are used to adjust the S_c as if the routed vessel was taking the comparison tracks.

End of voyage summaries are printed for each comparison ship and are compared with the actual route taken by the vessel. The end of voyage data is as follows:

Departure Time:	Time of departure in month-day-year and hour in Greenwich time from departure point. Note departure point may not be the port. For Yokohama, Nojima Saki is used as departure point.
Arrival Time:	Time of arrival at arrival point. Time is in month-day-year and hour in Greenwich time. Arrival point may not be at the actual destination. See comment on departure point above.
Time Enroute:	Difference between departure time and arrival time.
Distance:	Distance in nautical miles between departure point and arrival point.
Date:	Month-day-year.
Reported Positions:	Actual position reports from the vessel in latitude, longitude and Greenwich Mean Time in whole hours.
1200 GMT Position:	As determined by computer calculations and includes the effect of wind and sea upon the vessel's progress.
Daily Speed:	Speed made good between 1200 GMT positions.
Computed Average Weather:	Wind, sea and swell conditions as determined from the vessel's weather observation or by observations from other ships in the immediate vicinity.

Number of Days of Weather Conditions:	This matrix is based on the daily computed average weather and the vessel's heading.

The course actually followed by a ship, is a course recommended by Ocean Routes, Inc., for the particular transit at a specific departure time and is predicted ahead of time. The prediction is largely based on the 5 day USN weather forecasts, suitably interpreted by the routing computer program. Since the transits considered in this case study are approximately of 10 days duration the predicted course is also dependent on climatological data. The transit time associated with the recommended course is that logged by the actual transiting vessel.

The actual weather data for a region about the actual transit course is collected as the recommended transit proceeds. This weather information is collected from possibly 300-500 ships in transit of the North Pacific region at the same time as the vessel under study. These ship reports are supplemented by the reports of USN ships also in the region. The collected weather and sea state data covers the region of five alternative transits to be studied later by the computer program analysis. Hence within the limits of current weather structuring the weather for the selected region is known with certainty. Certainty is estimated to be a probability of 90% in predicting the weather sequentially, day by day, throughout the region of computer study of the five alternative transits. Using this perfectly known weather data, alternate courses are investigated, on the computer, and different transit times are generated. Usually one such course produces a faster transit than for the recommended course. Thus it is averred that if a <u>perfect weather forecast</u> had been available for the general transit region then the fastest time could have been selected instead of that time resulting from the recommended course.

The time difference between the recommended course transit time and the post facto fastest transit time is then the transit time incremental saving due to perfect weather forecasting.

Figure 7.1, illustrates the solid line recommended course, and the dotted post facto alternate courses.

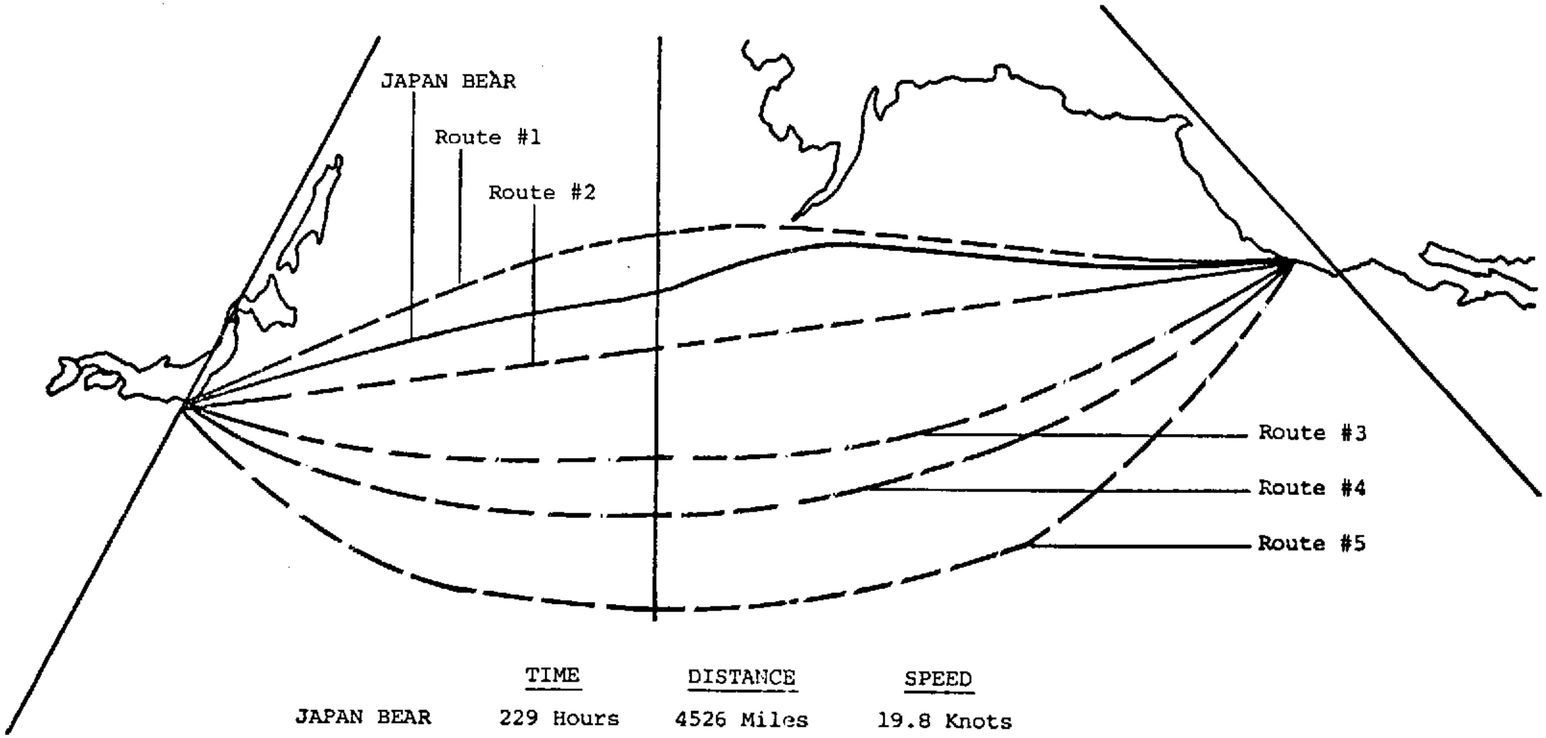
It is not evident, without further study, how the expected SEASAT 48$^+$ forecast of weather and sea state conditions with a 50% to 90% probability of being correct will modify the current mode of route selection. Neither is it evident how the forecasting parameters of accuracy and forecasting interval enter into the determination of how much of the transit time saving can be captured or realized.

Time savings derived in this study are related to the SEASAT operational capability of 1985 by assuming that with a fully operational SEASAT, perfect weather prediction will be possible when the expected processing for weather and sea conditions is fully implemented. The benefits that will be derived in the case study are therefore maximum benefits.

7.1.1.2.2 Optimum Routing of Freighters

In the section of the routing case study, transit time optimization was investigated for various types of freighters sailing between ports on the west coast of the United States and ports in Japan.

The shipping involved, carries containerized cargo; the ship types being C6 or Pacesetter, Lancer and Lash. In each transit considered, the vessels actual time enroute for a particular date of departure is compared with five alternate routes which are evaluated by the computer program. From the five alternate routes a fastest transit time is chosen. The difference between this time and the actual transit time of the ship in question is the maximum time saving assumed possible



	TIME	DISTANCE	SPEED
JAPAN BEAR	229 Hours	4526 Miles	19.8 Knots
Route #1	232 Hours	4609 Miles	19.9 Knots
Route #2	227 Hours	4472 Miles	19.7 Knots
Route #3	257 Hours	4612 Miles	17.9 Knots
Route #4	265 Hours	4711 Miles	17.8 Knots
Route #5	269 Hours	5087 Miles	18.9 Knots

Figure 7.1 Typical Transit Time Optimization Results

for this particular transit. This minimum time transit would have been the route recommended to the ship owners by a routing service, it is assumed.

A sample transit time investigation result is presented in Figure 7.1, showing route #2 at 227 hours to be the fastest computer time, which compared to the actual transit time of the LASH type JAPAN BEAR of 229 hours, produced a time saving of 2 hours or approximately 0.9% of the actual transit time. Figure 7.2 is the computer end of voyage summary for the same ship. This summary indicates the en-route daily weather conditions encountered by the ship in the computer's transit time model and indicates the daily ship speed that results. The speed in calm S_c indicated on Figure 7.1, is 20.5 knots.

The routing results for all the cargo ships in the study are listed in Table 7.1. Very simple statistics can be derived from Table 7.1 viz:

1. The maximum time saved is 5.3% of the actual time enroute; for easterly and westerly transits.
2. The maximum time saved in <u>westerly</u> transits is 3.4% of the actual time enroute.
3. The minimum time saved in <u>westerly</u> transits is 0% of the actual time enroute.
4. The maximum time saved in <u>easterly</u> transits is 5.4% of the actual time enroute.
5. The minimum time saved in <u>easterly</u> transits is 0% of the actual time enroute.
6. The <u>average</u> easterly time savings is 2.5% of the enroute time.
7. The <u>average</u> westerly time savings is 1.7% of the enroute time.
8. The <u>average</u> westerly and easterly time savings is 2.1% of the time enroute, or an average saving of 5.1 hours on an average transit of 241 hours duration.

Table 7.1 Cargo Ship Transit Times and Time Saving

Ship Name	Ship Type	Routing Date	Voyage Began	Voyage Ended	(1) Enroute Time	(2) Hours Saved
Japan Mail	C6	3/14/74	San Francisco	Yokohama	251	0
Oregon Mail	C6	3/21/74	Seattle	Yokohama	206	4
Washington Mail	C6	4/4/74	San Francisco	Yokohama	243	8
Japan Bear	Lash	3/18/74	San Francisco	Yokohama	229	2
President Jefferson	Pace Setter	5/9/74	San Francisco	Yokohama	249	3
Japan Mail	C6	4/30/74	San Francisco	Yokohama	247	6
Oregon Mail	C6	3/9/74	Yokohama	Seattle	208	7
Washington Mail	C6	3/21/74	Yokohama	Los Angeles	238	3
Philippine Mail	C6	3/26/74	Yokohama	Los Angeles	253	4
President Pierce	Pace Setter	3/10/74	Yokohama	Los Angeles	223	13
President Madison	Pace Setter	3/15/74	Yokohama	Los Angeles	226	6
President Jefferson	Pace Setter	3/29/74	Yokohama	Los Angeles	234	7
American Astronaut	Lancer	3/09/74	Kobe	Oakland	236	5
American Lark	Lancer	3/19/74	Yokohama	San Francisco	245	4
American Lancer	Lancer	4/04/74	Yokohama	San Francisco	223	11
Thomas Cuffe	Lash	3/23/74	Yokohama	San Francisco	217	9
Pacific Bear	Lash	3/30/74	Yokohama	San Francisco	214	5
Thomas Cuffe	Lash	5/5/74	Yokohama	Los Angeles	220	1
Japan Bear	Lash	4/25/74	Yokohama	Los Angeles	229	0
Washington Mail	C6	4/22/74	Yokohama	San Francisco	224	1
Philippine Mail	C6	5/9/74	Yokohama	Los Angeles	233	9

Hours saved as a percentage of normal hours enroute

Easterly transits	Minimum 0%	Average 2.5%	Maximum 5.3%
Westerly transits	Minimum 0%0%	Average 1.7%	Maximum 3.4%

(1) route actually sailed
(2) hours saved by fastest route

JAPAN BEAR — P.F.E. LINE

SAN FRANCISCO TO YOKOHAMA 2518

DEPARTURE TIME MAR 18 74 1700 GMT — DEPARTURE POINT 37.7N 122.7W

ARRIVAL TIME MAR 28 74 0600 GMT — ARRIVAL POINT 34.8N 140.0E

TIME ENROUTE 229 HOURS — DISTANCE 4526 MILES — AVERAGE SPEED 19.8 KNOTS

DATE MO DA YR	REPORTED POSITIONS	GMT	1200 GMT POSITION	DAILY SPEED	COMPUTED WIND/KTS	AVERAGE SEAS/FT	WEATHER SWELL/FT
3 19 74	41.6N 127.9W	12	41.6N 127.9W	17.6	N 22	7	NNW 7
3 20 74	45.9N 137.1W	12	45.9N 137.1W	19.8	NNE 18	3	NNW 5
3 21 74	50.1N 147.5W	12	50.1N 147.5W	20.3	SSE 16	3	WSW 5
3 22 74	52.7N 159.0W	12	52.7N 159.0W	19.0	SE 28	7	SSE 11
3/23/74	52.2N 172.0W	12	52.2N 172.0W	20.2	NW 12	3	WSW 8
3/24/74	50.8N 178.5E	06	50.4N 175.4E	20.2	NE 26	7	ENE 10
3/25/74	48.6N 166.6E	06	48.1N 163.8E	20.1	NNE 28	10	NE 11
3/26/74	44.8N 156.1E	06	43.7N 153.9E	20.2	NNW 21	5	N 8
3/27/74	40.0N 147.5E	06	38.8N 145.6E	20.0	NNW 15	3	NNE 7
3/28/74			34.8N 140.0E	19.1	N 31	10	W 13

NUMBER OF DAYS OF WEATHER CONDITIONS

	45KT	40KT	35KT	30KT	25KT	20KT	15KT	10KT	5KT	TOT
HEAD						.7		1.0		1.7
BEAM				1.0		2.0	1.0			4.0
FOLLOWING				2.0	1.0		1.0			4.0
TOTAL DAY				3.0	1.0	2.7	2.0	1.0		9.7

$S_c = 20.5$

Figure 7.2 Oceanroutes Inc.
Optimum Ship Weather Routing
End of Voyage Summary

Thus the small quantity of data obtained can be summarized in a very simple sense as follows:

On a Pacific Ocean transit between Japan and the ports of the United States West Coast which has an average duration of 241 hours by normal route selection methods, optimum routing with improved ocean condition forecasts obtained from SEASAT data will provide

- a minimum time saving of 0 hours
- an average time saving of 5.1 hours
- a maximum time saving of 13.3 hours

Then, if the hourly operating cost of a typical or average ship can be determined this time saving can be translated into a potential benefit per cargo ship transit of the Pacific routes of the study.

7.1.1.2.3 Typical Container Liner Operating Costs

The C6 or Pacesetter type vessel was chosen as being the typical of U.S. container liners operating in the Pacific. These vessels were recently constructed (1973) and will be at the mid-point of their operational life in 1985 when the SEASAT system will be operational.

The C6 or Pacesetter has recently entered service in the transpacific trade. These vessels are full container ships with a capacity of 1,098 20-foot container equivalents. Because the proportion of container sizes carried will vary from voyage to voyage (the mix of 20- and 40-foot units), it is assumed that the typical complement will be equal numbers of 20- and 40-foot containers on board. The specific characteristics are given in Table 7.2.

1973 costs for subsidized and unsubsidized C6 operation and for the first year and mid-life year are given in Tables 7.3 and 7.4, and show the changing importance of fixed costs and the value of the vessel at risk for hull insurance costs.

Table 7.2 C6 Characteristics	
Length, BP	625 feet
Beam	90 feet
Depth	53 feet
Draft, max.	33 feet
Shaft HP, max. install.	32,000
Shaft HP, normal	26,000
Specific fuel cons.	0.483 lbs/SHP-hr.
Speed	23 knots
Deadweight, max.	19,530
Displacement, max.	30,490
Gross tonnage	21,150
20-foot containers	366
40-foot containers	366 (732 20FE)*
Total containers	732 (1,098 FE)
Number in crew	39
Construction cost	$21.0 million
Construction subsidy	$10.3 million
Subsidized cost	$10.7 million

* FE foot container equivalents

Fuel costs were based on the Bunker C prices in San Francisco and Los Angeles on January 1, 1974 (including barging/pipeline charges). The costs for fuel have varied considerably recently. San Francisco and Los Angeles bunker prices increased from about $5.30 per barrel on October 1, 1973 to $12.30 per barrel on January 1, 1974, and then declined slightly to $11.73 per barrel as of April 1, 1974.

Table 7.3 C6 Daily Costs at Sea
(First Year Operation)

	Unsubsidized $	Unsubsidized %	Subsidized $	Subsidized %
Crew, subsistence	4,760	73.3	4,760	75.0
Stores and supplies	160	2.5	160	2.5
Maintenance and Repair	750	11.6	750	11.8
Insurance - Hull	580	8.9	440	6.9
- P&I	240	3.7	240	3.8
Total Subsidizable	6,490	100.0	6,350	100.0
After Subsidy	6,490	28.0	2,730	16.4
Miscellaneous	80	0.3	80	0.5
Fuel	10,970	47.4	10,970	66.0
Depreciation	2,270	9.8	1,130	6.8
Interest	3,350	14.5	1,710	10.3
Total	23,160	100.0	16,620	100.0

Tables 7.3 and 7.4 costs were developed from information specifically relating to C6 transpacific operation. Current schedules indicate that a fleet of four C6 vessels can maintain a weekly transpacific service (thirteen voyages annually per vessel); or, a C6 would provide about 9,500 container trips each way per year. It is estimated that the direct vessel costs are accurate to plus or minus 10 per cent in the aggregate, and plus or minus 20 per cent for component costs. No overhead or other indirect costs were included. These costs can total 25 per cent or more of direct vessel costs.

Hull and P&I costs were based upon a west coast broker's quotation for C6 vessels in transpacific service. The first year annual premium for an unsubsidized vessel was stated as one per cent of vessel value (10 per cent war risk, 40 per cent total loss, and 50 per cent partial loss). For subsidized or depreciated values at risk, the 10 per cent war risk and

Table 7.4 C6 Daily Costs at Sea (Mid-Life Operation)				
	Unsubsidized		Subsidized	
	$	%	$	%
Crew, Subsistence	4,760	74.8	4,760	75.8
Stores and Supplies	160	2.5	160	2.5
Maintenance and Repair	750	11.8	750	12.0
Insurance - Hull	450	7.1	370	5.9
- P&I	240	3.8	240	3.8
Total Subsidizable	6,360	100.0	6,280	100.0
After Subsidy	6,630	29.7	2,660	16.9
Miscellaneous	80	0.4	80	0.5
Fuel	10,970	51.2	10,970	69.7
Depreciation	2,270	10.6	1,130	7.2
Interest	1,740	8.1	890	5.7
Total	21,420	100.0	15,730	100.0

40 per cent total loss were scaled reflecting the value of the vessel in a given year. Referring to Tables 7.3 and 7.4, approximately $290 of the hull premium remained constant, reflecting U.S. transpacific operation and U.S. repair factors.

The P&I premium was quoted as $4.00 per gross ton per year of which approximately 50 per cent was due to crew and personnel liability, 30 per cent to cargo liabilities, and 20 per cent to miscellaneous liabilities (bumping docks, oil spills, etc.)

Depreciation and interest costs reflect 82 per cent debt financing used, interest on twenty-five year ship mortgage bonds, and twenty-five year straight-line depreciation. The mid-life, C6 hourly operating costs at sea, are as follows:

Unsubsidized	\$893/hr (1973\$)
Subsidized	\$655/hr (1973\$)

As a representative cost for this study, the mid-life subsidized rate of \$655/hr (1973\$) is selected.

7.1.1.2.4 U.S. Liner Cargo Trade

The 1973 Bureau of Census liner reports are not available yet; so the cargo flows and values are based on 1972 data from the Commerce publication FT 985-72-13, September 1973. Cargo values per long ton were estimated as an average of Los Angeles, San Francisco, Oakland, and Seattle dry cargo movements (route 29 terminals). The 1972 level movements and values are shown in Table 7.5. From Table 7.5 the number of cargo carrying both import and export for trade route 29 by U.S. liners in 1972 is 206,000 container equivalents. This figure can be translated into the number of transits of the Pacific easterly and westerly in 1972.

Table 7.5 1972 Trade Route 29 U.S. Liner Cargo Carryings

	Import	Export
Long tons (in thousands)	1,011	1,128
Estimated Value (in \$ millions)	668	417
Container Equivalents (in thousands)*	122	84

*Based upon 1971 MARAD data of 13.5 long tons per export container and 8.26 long tons per import container for U.S. ships on Trade Route 29.

7.1.1.2.5 Estimated Cost Savings for U.S. Ship Trade Movements Along Trade Route 29 for the Year 1972

The following data is used to estimate this savings:

1972 trade container equivalents	206,000
C6 vessel containers	1098 (20 ft. equivalents)
Number of route 29 transits per annum, i.e. (206,000)/1098	188
Average time saving per transit	5.1 hours
Mid life C6 vessel subsidized rate for hourly operating cost at sea	\$655/hr (\$1973)

U.S. ship average annual cost savings S_A dollars is given by

$$S_A = \begin{pmatrix}\text{Average time}\\ \text{Saving per}\\ \text{transit (hours)}\end{pmatrix}\begin{pmatrix}\text{Number of}\\ \text{transits}\\ \text{per annum}\end{pmatrix}\begin{pmatrix}\text{Hourly operating}\\ \text{rate, at Sea,}\\ \text{for ships}\end{pmatrix}$$

$$= 5.1 \times 188 \times 655 \ (\$1973)$$

or

$$S_A = \$0.63 \text{ million } (\$1973) \text{ per annum,}$$

or

$$S_A = \$0.69 \text{ million } (\$1974) \text{ per annum,}$$

The maximum U.S. ship average annual cost savings S_m dollars is approximately 2.5 times the average

or

$$S_m = \$1.58 \text{ million } (\$1973) \text{ per annum,}$$

or

$$S_m = \$1.74 \text{ million } (\$1974) \text{ per annum}$$

Thus the annual operating cost savings, based on 1972 trade for trade route 29 (North Pacific), for U.S. subsidized shipping, due to improved routing from SEASAT's 1985 operational capabilities will be less than \$1.71 million (\$1974) and in the average will be \$0.69 million (1974\$).

The cost saving determined will accrue to the shipping lines involved in the U.S. import-export trade along trade route 29. For the purpose of comparing the routing savings estimated with the at sea operating costs of the shipping, the at sea operating costs are $31.1 million per annum ($1974).

The cost savings, average or maximum, can exist only if the shipping companies integrate into their total operations all procedures required to take advantage of the "at sea" operating hours saved by optimum routing. This may not always be possible, because of non modifiable constraints, in the terminal operations.

7.1.1.2.6 Optimum Routing of Tankers

In addition to investigating the optimum routing of cargo ships operating in the northern Pacific, the optimum routing of tankers leaving the oil sources in the Persian Gulf for different international ports was also studied.

The procedure employed was essentially that for the cargo vessels, using Oceanroute Inc. routing procedures. The major difference between the cargo and tanker ships is the voyage distance and the speed of the ship. The cargo vessels operate efficiently at approximately 22 knots, the tankers at approximately 15 knots; the average transit time for the cargo ships was 230 hours and for the tankers it is 706 hours, reflecting both the lower speed and the greater transit distances.

Table 7.6 lists the results obtained from the process of optimum routing produced by the computer program. It is observed that each VLCC transit attempted was not successful in reducing the transit time. That is the alternate route investigated was slower than the route selected for the ship itself. It had been expected that the longer transit would produce a larger monetary savings. That it did not do so is probably attributable to an insufficient sample size and a choice of

Table 7.6 Tanker Ships Transit Times and Time Savings						
Ship Name	Ship Type	Routing Date	Voyage Began	Voyage Ended	Enroute Time (Hours)	Hours Saved
William H. Allen	Medium Size Tanker	2/14/74	Singapore	San Francisco	560*	19
Howard W. Bell	VLCC	8/16/74	Ras Tanura	Freeport Bahamas	757	-17
Paul L. Fahrney	VLCC	8/6/73	Rasalhadd	Saint John N.S.	752	-27
J. T. Higgins	VLCC	7/20/73	Persian Gulf	Europort	737	-38
James O'Brien	VLCC	9/22/73	Persian Gulf	Europort	726	-25

*The fastest time for the William H. Allen determined by the routing program required only 521 hours or a saving of 39 hours from the actual route.

This solution was considered to be unacceptable because of its northerly passage through cold waters which would have affected the crude oil viscosity adversely.

time of the year in which the South Atlantic is relatively calm. It is intended to investigate this routing problem further, in the future.

7.1.1.2.7 Marine Insurance Results

7.1.1.2.7.1 Introduction

This source of possible benefits from SEASAT is assumed to be related to insurance premium reductions that can be reasonably made on the basis of reduced heavy weather encounter by shipping. It is therefore to that part of marine insurance where weather can be assumed partially responsible for the premium determination that this part of the study is addressed.

7.1.1.2.7.2 Reductions in Marine Insurance Premium Due to SEASAT

By extrapolating annual marine insurance premium payments made by the world deep-water ocean shipping fleet over the last 15 years, Klimberg [128] estimates that in the year 1985 these payments will reach $698 million per annum (1974 dollars). According to Kirman's [1] study of the marine insurance industry, a third of every premium dollar is attributable to:

1) fortuitous or "uncontrollable" losses, 2) underwriting costs and profits, and 3) "preventable" losses. Both types of losses may be decreased by improved weather forecasting. Any reduction in losses is assumed to result in a corresponding decrease in premium payments.

Klimberg cites U.S. Coast Guard data for the ten year period 1963-1973 as indicating that on the average 13% (with an annual low of 8% and a high of 17%) of marine losses (in dollars) are "primarily" caused by adverse weather conditions while weather is a "significant contributing factor" in an additional 13%.

Thus the preventable losses alone amount to 1/3 x 698 = $233 million, and about 26% of that or $61 million is attributable to adverse weather. These are the total preventable losses which may be affected by improved weather information. Assuming that between 20% and 50% of these losses may be eliminated by routing undertaken as a result of SEASAT data, Klimberg concludes that between $10 and $30 million a year (.2 x 61 to .5 x 61) may be saved in <u>world wide</u> insurance premimums in the 1985 era.

This estimate is conservative since it does not include savings due to reduction in currently "fortuitous" losses or savings arising from extensions of nominal ship life which might result from improved weather forecasts.

Supportive data for the above estimates, taken from Klimberg [128], are included below.

<u>Ocean Marine Insurance Costs</u> Marine insurance is written for three exclusive categories: 1) Hull, 2) Protection and Indemnity (P & I) and 3) Cargo.

The ocean marine premium for <u>hull and cargo</u> written in the <u>American market</u> have exhibited a steady growth to the all time high of 550 million for 1972. Data published in

[2] Insurance Facts 1973 Edition, Insurance Information Inst. N.Y., N.Y. 1974, (taken from Best's Aggregates and Averages) is further analyzed in Table 7.7, which shows 5 year averages, rounded out to millions and the % increase of each 5 year period over the previous one.

The U.S. subsidy programs for ship construction and operation with requirements to insure up to 75% in the American market will continue to cause these figures to grow in the next decade. An extrapolation for the next 15 year period is shown in Chart A for three assumptions of growth rate.

Based on this, and in view of the rising investment in large ships, the continuing U.S. construction program, the inflationary trends, a figure for 1985 of $1 billion (1974) dollars appears conservative. This will be taken as the estiate of the U.S. share of the ocean marine insurance dollar in 1985.

Using data from the Kirman Report [1] the total U.S. ocean marine premiums may be adjusted to reflect only the portion pertaining to deep-water commerce. In 1969 Kirman found that about 1/2 of the figure for annual hull, cargo and P and I insurance premiums were unrelated to world commerce. Using this factor and projecting to 1985, we may establish the figure for deep-water ocean marine hull and cargo U.S. market premiums at $500 million annually.

Table 7.7 American Ocean Marine Hull and Cargo Premiums

Period	Average Annual Cost of Premiums (Millions)	Percent Increase Over Previous 5 Year Average
1948-1952	161	-
1953-1957	177	10%
1958-1962	226	28%
1963-1967	275	22%
1968-1972	457	66%

Period	Assuming Increase at 1968-1972 Rate (1.66) Avg. Annual Cost of Premium (Millions)	Assume Increase at 1/2 Rate of 1968-1972 Period (1.33)	Assume Rate= 1958-1972 (2.02) Over 15 Year Period
1973-1977	758	608	-
1918-1982	1259	808	-
1983-1987	2090	1075	924

Chart A.

Estimate of American Hull and Cargo Premiums

Considering now the information concerning the division of the market between the U.S. insurance companies and the world market (principally England), the Kirman study found the following division of insurance dollars:

Hull - 25% foreign
Cargo - 43% foreign
P & I - over 50% to London,

while the 1970 total premium dollars were divided according to the following:

Hull - 25.5%
Cargo - 59.2%
P & I - 15.3%

Chart B illustrates the application of these percentages to the 1985 insurance premiums.

The Coast Guard data, Statistical Summary of Casualties to Commercial Vessels, carries a listing "Primary Cause" which categorizes the 17 data packets included under their heading "Nature of Casualty". The casualty figure for FY73 for "adverse weather" is shown to be 259. Clearly, adverse weather and ocean dynamics generally may be significantly involved as a primary or secondary factor in such causes as:

Chart B Division of Premium Dollars, Ocean Marine Insurance		
Total deep-water ocean marine U.S. premium dollars, 1985 era - $500 million/yr.		
Type of Insurance		Premium Dollars
Hull	= 25.5% x 500 m =	127.5 m
P & I	= 15.3% x 500 m =	76.5 m
Cargo	= 59.2% x 500 m =	296.0 m
	Total =	500 m
Foreign hull premiums	= 25% x 127.5 =	31.9 m
Foreign P & I premiums	= 50% x 76.5 =	38.3 m
Foreign cargo premiums	= 43% x 296 =	127.3 m
	Total =	197.5 m
Total deep-water ocean marine premium dollars, 1985 era - U.S. and Foreign - $698 m (1974 dollars).		

"fault on part of other vessel or person", "unusual currents", even "personnel faults".

If for simplification, we regroup the 17 packets called "Nature of Casualty" to 7, the distribution of the 259 adverse weather casualties is as shown in Table 7.8.

The U.S. Coast Guard reports include estimated costs based on on-the-spot assessments of damage prior to repair, dry-dock inspection etc. Cmdr Lauridsen, in charge of the USCG data bank, suggested experience has shown that the reported figures on damage are generally too low, and the dollar values in the statistical summaries should be multiplied by 3 to approach realistic levels. (This includes damage unseen at the time of the occurrence of the casualty, tow charges, etc.) The FY73 "Estimated Losses" may be found on page 7-33. Listings are in thousands of dollars.

All the losses due to Adverse Weather as a primary cause are not directly obtainable from the Annual Summary. However, a figure is given for the Column E type casualties of Table 7.9. Using this estimated cost information, and applying the experience factor of 3, we get the annual costs of the 51 casualties, of Category E, to be presented in Table 7.9.

Table 7.8 Distribution of 259 "Adverse Weather" Casualties, FY73 (U. S. Coast Guard Data Base)								
	Nature of Casualty							
	A	B	C	D	E	F	G	
	Collisions	Explosions	Groundings	Founderings Floodings	Heavy Weather Damage	Cargo	Material Failure & Other	Total
Adverse Weather Prime Cause	93	1	63	19	51	8	24	259

Table 7.9 Estimated Costs (1973) Heavy Weather Damage Category				
Costs of "E"	$890,000	Vessel	Suggested	$2,670,000
Alone	1,076,000	Cargo	Experience	3,228,000
C.G.	125,000	Property	Factor = 3	375,000
(Estimate)			Total	= $6,273,000

The Heavy Weather Damage (Category E) constitutes about 20% of the 259 casualties listed as "primary cause - weather". Total vessel, cargo and property damage for the category may be extrapolated. (Table 7.10).

The Estimated Losses for all FY73 casualties is

Vessel	- $81,894,000
Cargo	- 16,839,000
Property	- 34,838,000
Total	=$133,571,000

If we apply the experience factor 3, this becomes approximately $400 million dollars for FY73. The estimate of "adverse weather" costs, as a % of total losses, equals

$$\frac{31.4}{400} = 7.8\%$$

Table 7.10

Estimate of Adverse Weather Costs, FY73

Total Estimates Category E Heavy Weather	- $6,273,000
Number of Casualties Attributed to Adverse Weather as Prime Cause	- 259
Number of Casualties Classified as Heavy Weather	- 51
Category E as a % of all Adverse Weather Casualties	- 20%
Estimate of All Adverse Weather Casualties Based on Costs of Category E = 20% of Total (includes experience factor of 3)	- $31,365,000

(This compares with the ratio of the number of casualties whose primary cause is Adverse Weather, 259 and all casualties, viz.,

$$\frac{259}{3108} = 8\%$$

How representative is the FY73 data for "adverse weather - primary cause" casualties in terms of the total casualties? The pertinent U.S. Coast Guard data for the past 10 years is summarized in Table 7.11.

Table 7.11 shows 8% to be too conservative. However, the "total casualties, 1973" appears to be a 10 year high. To develop an average figure, the total losses for the past five years are presented in Table 7.12.

Ocean cargo insurance with an average rate of 30-40¢ per $100 of cargo, though a small cost, is one which large shippers are interested in controlling. Premium cuts of 10-25% to large shippers using containers are not directly related to savings on losses. Kirman breaks out the premium on average rates of 30¢ (per $100 of cargo) as follows:

1/3 = 10¢ for fortuitous, uncontrollable losses (sinking, stranding, etc.)

1/3 = 10¢ for costs

1/3 = 10¢ for preventable losses

Table 7.11 Annual Statistics of Casualties
U. S. Coast Guard Data Base --
Commercial Vessels

	Fiscal Years									
	73	73	71	70	69	69	67	66	65	65
Total Casualties	3108	2424	2577	2582	2684	2570	2353	2408	2170	2308
Vessels Total Lost as Percent of Casualties	10	13	14	13	14	13	12	15	12	17
Adverse Weather Listed as "Primary Cause" No. of Casualties	259	256	370	274	253	446	202	374	244	274
Adverse Weather as Primary Cause as % of Total Casualties	8	11	14	11	9	17	9	16	11	12

Source: Dept. of Transportation, U. S. Coast Guard

The part of the premium upon which improvement in experience is operative, is the last item. Thus, for a 20% cut in overall premium (6¢ - 20% of 30¢), a 60% cut in preventable losses would have to be demonstrated (or 6¢ ÷ 10¢ = 0.60).

The discussion of preventable losses shows the dependency of this term on state of the art in the carriage of goods. 5% of the vessel tonnage was lost in 1966 because vessels simply are not impervious to ocean perils. The risk of considering any loss fortuitous is that parties will not be directly motivated to reduce the probability of occurrence. The crudeness of underwriting segregation of losses is noted. For example, in many instances an underwriter does not even examine an account unless the loss ratio changes significantly. For example, a standard criterion is a 40% loss ratio: if the ratio is greater, money is being lost, therefore experience should be looked at. Several companies are beginning to segregate loss information in a rational manner, however.

Changes in marine underwriting occur slowly; marine underwriters are inherently conservative. Critique of the above estimate:

Table 7.12 5 Year U.S. Coast Guard Estimated Losses (Total of all Casualties) and Estimated Average Cost for Adverse Weather (Costs in Thousands of Dollars)

Fiscal Year:	1973	1972	1971	1970	1969
Vessel	81,894	82,475	78,961	69,274	68,267
Cargo	16,839	12,866	6,629	17,360	10,269
Property	34,838	11,106	8,911	10,629	7,926
Total	133,571	106,446	94,501	97,263	86,462

Avg. 5 years $101.6 million

Applying Experience Factor (x3) - Average Costs = $305 million

Adverse Weather Costs = >8% = <$24 million per year.

1. Better information on the validity of the U.S. Coast Guard experience factor is needed. Checking with several people, other estimates were obtained in the range of from "2 to 3" times the published cost data. A sampling made of actual costs, against the reported figures would be needed to improve the figures.

2. The actual computer summation of costs for the adverse weather category can be obtained. This would eliminate the need for the estimate made in Table 7.11.

3. The 8% figure appears to be too low. Examining Table 7.12, a figure of 11% would be more appropriate as the percentage of all casualties falling into the adverse weather region.

4. Taking 1, 2, and 3 into consideration, the estimated costs are believed to be conservative. The means are at hand for an improved estimate, however.

5. Further considerations:

   a. The improved estimate would also include weather-related casualties as well as those casualties occurring which have been categorized as "Primary Cause - Adverse Weather".

b. The qualification should be made that the ship population in the U.S. Coast Guard data bank covers ships which are berthed in the U.S. and have accidents in or near U.S. ports and U.S. ships anywhere in the world. To this population must be added the number of foreign flag ships carrying U.S. commerce, not reporting in this data bank, which affect U.S. commerce and its competitive position in world trade.

7.1.1.2.8 Case Study Results Summary

7.1.1.2.8.1 Cargo Ship Routing

SEASAT will produce an annual operating cost savings for U.S. subsidized shipping working the North Pacific trade route 29 which will be less than $1.74 million (1974$) and which in the average will be $0.69 million (1974$), based on 1972 U.S. trade.

7.1.1.2.8.2 Tanker Ship Routing

Since only one of five tankers transit times was reduced by attempted routing, no cost savings for tankers operating between the Persian Gulf and international ports is assumed for SEASAT capabilities at this time.

7.1.1.2.8.3 Marine Insurance Premium Reduction

The case study estimates that world wide shipping in 1985 may enjoy an integrated insurance premium reduction per annum that is between $10 million and $30 million (1974$). These values arise in the category of preventable losses for marine insurance and represent estimates of the portion of preventable losses that result from heavy weather encounters by shipping. It is conjectured that another marine insurance category of fortuitous loss may produce premium savings because of extensions to ship operating life that result from diminished encounters with heavy weather. <u>No monetary estimates were, however, made of this possible source of benefits</u>.

7.1.2 The Model - Shipping Supply and Demand

The model used to estimate the benefits of SEASAT to optimum ship routing is developed in this section. The results presented are considered to be preliminary as the depth of this analysis was limited by the schedule set for this initial economic assessment. The economic analysis and results of this model are followed by a discussion of the type of econometric model toward which this brief study should be extended to obtain a more thorough analysis of the benefits in this area.

As indicated in Section 5.1, the demand for shipping is a demand derived from the demand for trade. The demand for trade flows is examined first. Initially, a square trade matrix X is defined (R=K) only for computational ease at a later stage. The essential analysis will not be affected if the matrix is not square.

$$X_t = \begin{bmatrix} x_{11t} & x_{12t} & \cdots & x_{1Kt} \\ x_{21t} & & & \vdots \\ \vdots & & & \vdots \\ x_{R1t} & \cdots & \cdots & x_{RKt} \end{bmatrix}$$

where

x_{rkt} is the quantity in long tons of exports (or imports) on trade route r of commodity k in year t.

Therefore, the sum along each row represents the total trade on route r

$$\sum_{k=1}^{K} x_{rkt} = w_{rt}$$

where

w_{rt} is the total quantity in long tons of exports (or imports) on trade route r in year t.

Summing down each column, the total trade in any one commodity is

$$\sum_{r=1}^{R} x_{rkt} = w_{kt}$$

where

w_{kt} is the total quantity in long tons of exports (or imports) of commodity type k in year t.

The total growth in exports (or imports) is represented as a simple function of time by the function

$$w_{rt} = a_o + a_1 t^{\beta}$$

Once this equation gives the total exports on a trade route in a given year, the portion of this trade consisting of each type of commodity is determined.

A standard method for such a problem is the share-of-market (SOM) analysis. Under the usual SOM analysis, the present portion of a total market which is held by some submarket is assumed to remain constant. Once the total market growth is estimated, the size of the submarket can be determined directly as the product of its proportionate share and the total size of the market. The disadvantage of this method is that the share is assumed to be constant over time.

A variation of the SOM employs a Markov chain. In the Markov chain, it is assumed there is some fixed probability of change in the market share of each submarket with time.

In order to derive the fixed probability of change, resort is made to a standard quadratic programming algorithm by Wolf, Lee, Judge, and Zellner see [87]. This provides the basic model as the set of matrices

$$Z_{rt} = A_r \, Z_{r(t-1)}$$

where

Z_r is the normalized trade row matrix (or market share matrix) on route t derived from matrix X.

A_r is the fixed probability of change matrix for route r.

Using the quadratic programming algorithm, one can solve for A_r. This may be recognized as the more familiar Markov chain in a broader framework by stringing out the rows in the X matrices after normalizing each row to form a single row vector with dimension [1 x (R x K)] and defining the transition matrix as a [(R x K) x (R x K)] matrix of the form

$$A=\begin{bmatrix} A_1 & O & \cdots & O \\ O & A_2 & & \vdots \\ \vdots & & \ddots & \vdots \\ O & & & A_R \end{bmatrix}$$

If this rate of change in the SOM stays fixed over time, one can estimate the future normalized market shares by

$$\hat{Z}_{rt} = \hat{A}_r^t \, Z_{r1}$$

We can get the final trade flow estimates by

$$\hat{X}_t = W_t \, \hat{Z}_t$$

where

W_t is the matrix consisting of the w_{rt}'s on the diagonal and zeros off the diagonal

$\hat{Z}_t$ is the general transition matrix consisting of the submatrices $\hat{Z}_{rt}$'s.

From these estimates of the trade in tons by commodity by route, the shipping demand is derived by multiplying the appropriate distances

$$\hat{Q}_t^D = D_r \, \hat{X}_t$$

where

$\hat{Q}_t^D$ is the matrix consisting of q^D (or the demand for shipping a given commodity on a given trade route in one year a distance of d_r), in ton miles;

D_r is the matrix with distances along each trade route, d_r, on the diagonal and zeros off the diagonal, in miles.

By assuming the present freight rates, f, remain constant in the future, the total benefits can be estimated as the decrease in the total freight cost, C, involved in supplying this shipping requirement. The analysis by which this is accomplished is examined in the next section.

7.1.3 Economic Analysis

In the previous section the method for deriving shipping demand was developed. The demand for shipping is a function of the economic activity, the populations and the relative prices in the trading regions. If the freighting cost is always small compared to the goods being transported, freight rates will have an insignificant impact on the demand for shipping and the demand for shipping is not a function of freight rates. An econometric model will be proposed below which will incorporate these demand elements.

On the other hand, the freight rate is very sensitive to the supply of shipping at any one time and, simultaneously, the supply of shipping is a function of the present and past freight rates. This relationship is illustrated in Figure 7.3a.

In the present study it is assumed that the freight rates remain constant over the planning horizon. The functional relationship discussed in the previous paragraph, by which freight rates are a function of both the supply and demand for shipping, is incorporated in the proposed extended econometric method.

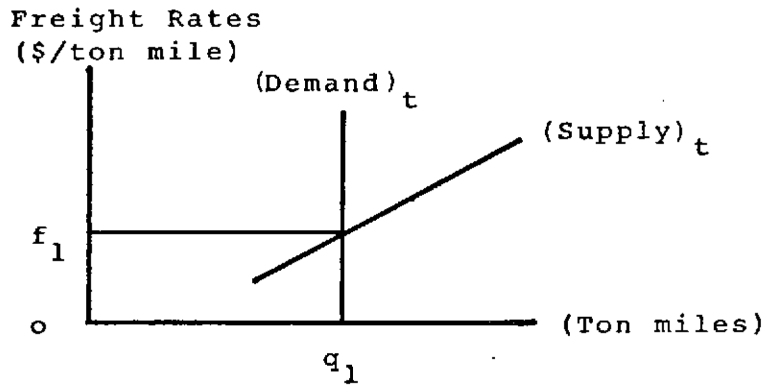


Figure 7.3a Shipping Supply and Demand

Since the freighting cost must be added to the cost of the products shipped, any freighting cost saving may potentially be passed onto the consumer of the product and added to his consumer surplus. The sequence referred to here would involve better ocean condition forecasting by SEASAT, less damage and fuel and other operating costs for shippers, lower freight rates for shipping commodities, and lower prices to consumers of the commodities. A more interesting market structure may be found in the case of oil than for most commodities, and so a more detailed economic analysis of this process is given for the Alaskan oil case in Section 7.4.3 below. In general, the decrease in the cost of shipping is assumed to be equal to a gain in consumer surplus. This gain in consumer surplus is equal to the decrease in freight rates times the quantity of goods shipped and is defined here as a potential benefit from SEASAT ocean condition forecasting in the area of optimum ship routing. The remainder of this section describes the method of quantifying this benefit.

It is worth repeating here what is meant by Optimum Ship Routing (OSR), sometimes referred to as Optimum Track Ship Routing. This time it is, however, defined by what it does not mean. It does not refer to attempts to route ships for the purpose of spreading traffic more evenly and to lessening queueing problems at ports. Such aggregate schemes work on an integrated basis with some central authority directing ship movements to some degree. Details of recommendations for such a scheme may be found in Inter-Governmental Maritime Consultative Organization (89). The economic benefits and costs of such a scheme are evaluated in McKenzie (90).

In this study, ocean routing refers to the micro-economic operation of a vessel in which ocean condition forecasts from SEASAT are employed to route the ship to minimize the cost of a transit. The value of SEASAT information in dockside operations is evaluated elsewhere in this study. The specific impact is on the cost side: cost items which are time dependent such as labor; cost items which are damage dependent such as hull and cargo. If insurance is used as a proxy to measure the damage costs such a consideration as loss of ship should not be counted as a benefit. This is because insurance also covers loss of a ship or life. Therefore, to include both of these as costs would involve double counting. It is, of course, possible to separate the portions of insurance which go to hull, P & I, and cargo and develop benefits consistently.

There are two aspects of the potential benefits which must be quantified. The first of these is the amount of benefits which we may reasonably expect to capture in the long run. This depends on many variables such as satellite information, the country regulating a particular ship and the training of its seamen, area in the seas in which a ship operates, the time of year, the type of ship, etc. All of these factors also impact on the second aspect of benefit quantification which we are considering here. This is the "rate of learning" or the speed at which the long run benefit is realized. Ultimately, any estimate of the benefits due to the decrease in cost of shipping and freight rates must depend on quantification of these two aspects.

In this report the case study method was utilized to quantify the first aspect. This was supplemented by a survey of the literature. The output from these exercises was an estimate of the benefits in terms of cost reduction which might be captured in the long run by the use of SEASAT information of ocean conditions. This is expressed as a per cent of the freight rate in tons per thousand miles.

In the process of deriving the quantification of the captured benefits, insight was gained into the second aspect of the problem - the rate of implementation of the SEASAT data ocean condition forecasts for OSR. Essentially, the rate of implementation was derived subjectively. Knowledge of the particular environs in the case study and familiarity with the literature pertaining to similar studies enabled a fairly reasonable estimate to be made. The quantification of these two aspects was expressed in the formula (see Figure 7.3b)

$$\hat{\delta}_{rt} = \hat{c}_r - \left(d_r\right) / \ t$$

where

$\hat{\delta}$ - percentage decrease in freight rate which is captured by use of SEASAT forecasts on route r in year t

c - maximum percentage decrease in freight rates which may be captured by use of SEASAT forecasts

d - coefficient (with no significant interpretation) which determines rate at which c is approached over time

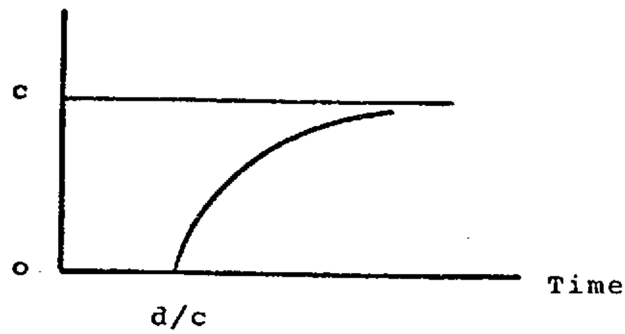


Figure 7.3b Freight Rate Decrease Capture

In the previous section the demand for shipping q_{rkt} was derived which in matrix notation was Q_t^D. If we define the freight rates on a given route r for a given type vessel k in year t as f_{rkt}, we get

$$C\,(I)_t = \sum_r \sum_k f_{rkt}\, q_{rkt}$$

where

C - shipping cost matrix (one by one).

The (I) is the baseline case, or the costs before SEASAT. If the operation variable $\hat{s}_{rt}$ is defined as

$$\hat{s}_{rt} = (1-\hat{\delta}_{rt})$$

where s is interpreted as the ratio of freight rate without SEASAT forecasts to the freight rate with SEASAT forecast.

Finally the shipping costs with SEASAT were defined as

$$C(II)_t = \sum_r \sum_k f_{rkt} \quad q^D_{rkt} \quad \hat{s}_{rt}$$

and the benefits of SEASAT information to Optimum Ship Routing are

$$B = \left[C(II)_t - C(I)_t \right]$$

7.1.4 The Data and Results

The case study of Optimum Ship Routing discussed at the beginning of the chapter covered 21 crossings on five routes across the Pacific. The generalization of these results using the model developed in the previous two sections was carried out for selected U.S. trading partners across the Pacific and the North Atlantic. These partners were:

1. United Kingdom
2. West Germany
3. France
4. The Netherlands
5. Ireland
6. Belgium-Luxemberg
7. Sweden
8. Denmark
9. Japan
10. Taiwan

Ideally trade would have been analyzed on a commodity by commodity and route by route basis rather than a country by country basis since the distances between the various parts of the U.S. and some of its partners could be quite different. Unfortunately the trade data cross classified by route and commodity type is not readily available. The U.S. Bureau of the Census tapes, SA705 (exports) and SA305 (imports), are available for sale but the data are in highly disaggregate form and would require a substantial programming effort to consolidate the data into route by route form.

The U.S. Maritime Administration generates internally for the years since 1969, an ideal report for the purpose of this study. It is called U.S. Oceanborne Foreign Trade Annual Comparisons by Trade Route [215]. This report is also prepared on a quarterly basis. The computer output layout is given in Table 7.13. Since the commodity codes are according to Census A and B schedules to three digits, it is only necessary to use the Planning Research Corporation Study [184] cross-classification table to group the commodities into the 19 Transport Homogeneous Groups (THG) by trade route, i.e., to group trade by commodity type by route as required in the model. The Maritime Administration has recently supplied this data for the purposes of this study and it will be utilized in the follow-on to this preliminary assessment.

With trade route data, it would be possible to utilize structural variables, such as income, prices, and population in the regions at the terminal points of each trade route to explain trade flows and the demand for shipping. The Bureau of Economic Analysis in the U.S. Department of Commerce has grouped the U.S. into 173 suitable regions and collected the corresponding data in this form (see Figure 7.4). This type of regional data is published each year in the April and August issues of the U.S. Department of Commerce's Survey of Current Business. It is not necessary to have as fine a breakdown of any of the U.S.'s trading partners. In most cases, country level data would suffice. The U.S. foreign trade routes are reproduced here also, Table 7.14.

With the limitations discussed above, the following data and procedure were employed. Estimates of trade in tons with ten U.S. partners were made for the years 1987, 1992, and 1997 based on the volume of trade from 1965 to 1972, Table 7.15. The composition of commodities was assumed to remain constant with each trading

Table 7.13 U.S. Oceanborne Foreign Trade Quarters Comparisons by Trade Route, example comparison report

Exports

1. Trade Route	2. Type Cargo	3. Comm Code	4. Commodity Description	5.	6.	7.	8.	9.	10.
				--------------Volume--------------			----------% U.S. Volume----------		
				--------------Value--------------			----------% U.S. Value----------		
				Current Yr. Qtrs.	Prior Yr. Qtrs.	Prior Yr.	Current Yr. Qtrs.	Prior Yr. Qtrs.	Prior Yr.

1. Trade Route number designating trade route or trade route subdivision.
   Examples: 1200 - U.S. Atlantic/Far East
   1201 - U.S. Atlantic/Japan
   1202 - U.S. Atlantic/Republic of Korea
   etc.

2. Type Cargo - 5-general cargo
   6-dry bulk cargo
   7-liquid bulk cargo

3. Commodity Code designation according to Census A(Imports) and B(Exports) schedules to 3 digits

4. Commodity Description - Alphabetic rendition of column 3.

5. Volume and Value: Current Year Quarters - Total long tons (2240 lbs.), followed by total $ value, of cargo carried by U.S. and foreign flag vessels in period indicated.

6. Volume and Value: Prior Yr. Quarters - Total long tons, followed by total $ value, of cargo carried by U.S. and foreign flag vessels in period indicated.

7. Volume and Value: Prior Yr. - Total long tons, followed by total $ value, of cargo carried by U.S. and foreign flag vessels in year indicated.

8. % U.S. Volume and % U.S. Value: Current Yr. Quarters - Percent of total long tons, followed by percent of total $ value, of cargo carried by U.S. flag vessels in period indicated.

9. % U.S. Volume and % U.S. Value: Prior Yr. Quarters - Percent of total long tons, followed by percent of total $ value, of cargo carried by U.S. flag vessels in period indicated.

10. % U.S. Volume and % U.S. Value: Prior Yr. - Percent of total long tons, followed by percent of total $ value, of cargo carried by U.S. flag vessels in year indicated.

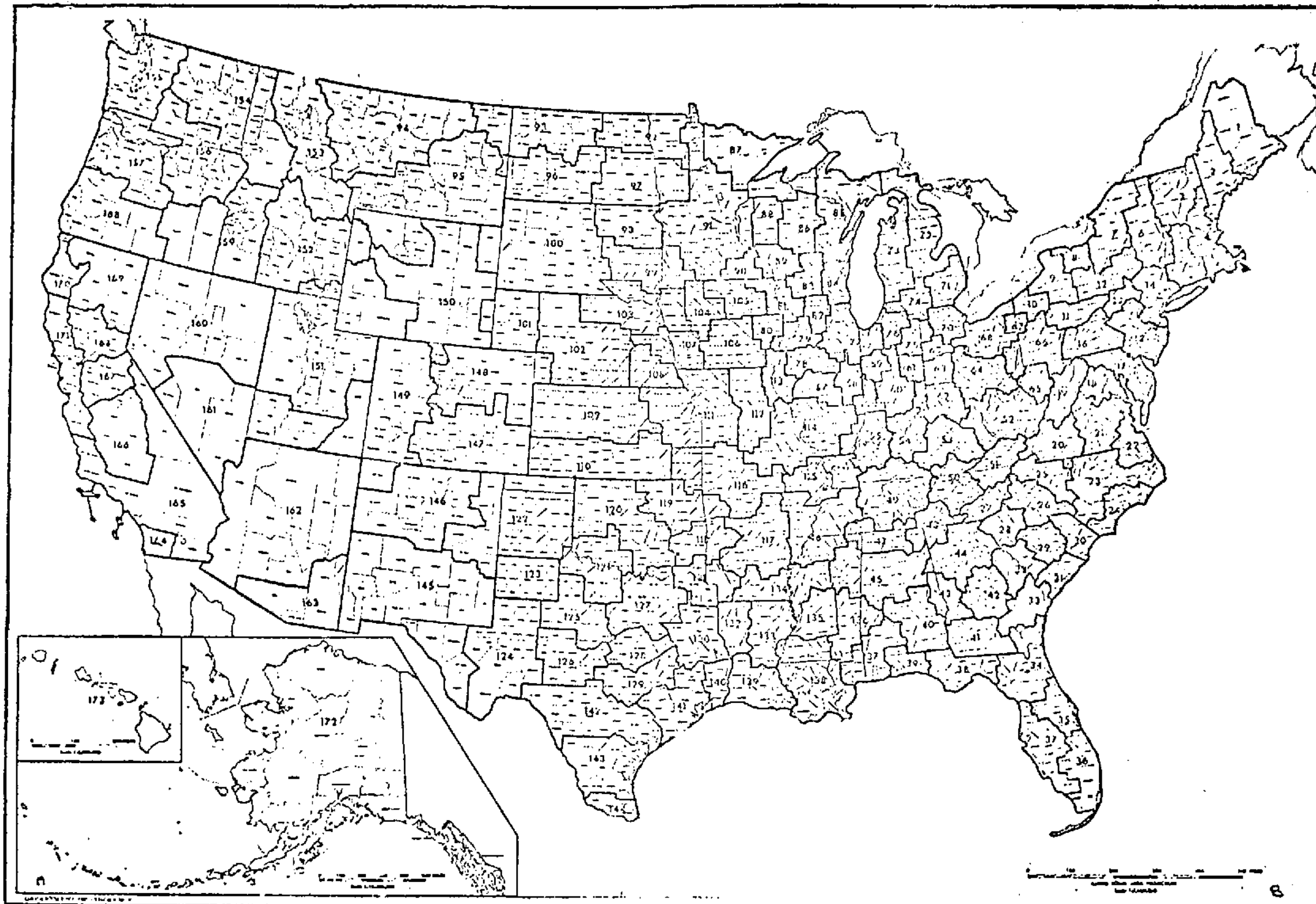


Figure 7.4 BEA Economic Areas

Table 7.14 Trade Routes of the U.S.*

Trade Route Number	1973 Description
0100	U. S. Atlantic/East Coast South America
0101	U. S. Atlantic/Brazil
0102	U. S. Atlantic/Uruguay
0103	U. S. Atlantic/Argentina
0200	U. S. Atlantic/West Coast South America
0201	U. S. Atlantic/Colombia (West Coast)
0202	U. S. Atlantic Ecuador
0203	U. S. Atlantic/Peru
0204	U. S. Atlantic/Chile
0400	U. S. Atlantic/Caribbean (Incl. Cristobal), East Coast Mexico
0401	U. S. Atlantic/Mexico (East Coast)
0402	U. S. Atlantic/Colombia (Carib.)
0403	U. S. Atlantic/Venezuela
0404	U. S. Atlantic/Netherlands Antilles
0500	U. S. North Atlantic/United Kingdom, Ireland (Eire)
0600	U. S. North Atlantic/Scandinavia and Baltic (Incl. Nlfd., Greenland & Iceland)
0700	U. S. North Atlantic/West Germany (North Sea)
0800	U. S. North Atlantic/Netherlands, Belgium
0801	U. S. North Atlantic/Netherlands
0802	U. S. North Atlantic/Belgium
0900	U. S. North Atlantic/France (Atlantic), Spain (N. of Portugal)
0901	U. S. North Atlantic/France (Atlantic)
0902	U. S. North Atlantic/Spain (N. of Portugal)
1000	U. S. North Atlantic/Mediterranean, Black Sea, Portugal, Spain (South of Portugal). Morocco, and Azores
1001	U. S. North Atlantic/France (Med.)
1002	U. S. North Atlantic/Spain (S.E. of Portugal & Med.)
1003	U. S. North Atlantic/Portugal
1004	U. S. North Atlantic/Italy
1005	U. S. North Atlantic/Yugoslavia
1006	U. S. North Atlantic/Greece
1007	U. S. North Atlantic/Turkey
1008	U. S. North Atlantic/Syria
1009	U. S. North Atlantic/Lebanon
1010	U. S. North Atlantic/Israel (Med.)1011
1011	U. S. North Atlantic/Egypt (Med.)
1012	U. S. North Atlantic/Libya, Tunisia, Algeria, Morocco

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Table 7.14 Trade Routes of the U.S.* (continued)

Trade Route Number	1973 Description
1100	U. S. South Atlantic/United Kingdom and Ireland (Eire), Continental Europe North of Portugal
1101	U. S. South Atlantic/United Kingdom, Ireland (Eire)
1102	U. S. South Atlantic/Spain (N. of Portugal)
1103	U. S. South Atlantic/France (Atlantic)
1104	U. S. South Atlantic/Belgium
1105	U. S. South Atlantic/Netherlands
1106	U. S. South Atlantic/West Germany (North Sea)
1107	U. S. South Atlantic/Scandinavia and Baltic
1200	U. S. Atlantic/Far East
1201	U. S. Atlantic/Japan
1202	U. S. Atlantic/Republic of Korea
1203	U. S. Atlantic/Okinawa
1204	U. S. Atlantic/Taiwan
1205	U. S. Atlantic/Hong Kong
1206	U. S. Atlantic/Philippines
1207	U. S. Atlantic/South Vietnam
1208	U. S. Atlantic/Thailand
1300	U. S. South Atlantic and Gulf/Mediterranean, Black Sea, Portugal, Spain (South of Portugal), Morocco, and Azores
1301	U. S. South Atlantic and Gulf/France (Med.)
1302	U. S. South Atlantic and Gulf/Spain (S.E. of Portugal and (Med.)
1303	U. S. South Atlantic and Gulf/Portugal
1304	U. S. South Atlantic and Gulf/Italy
1305	U. S. South Atlantic and Gulf/Yugoslavia
1306	U. S. South Atlantic and Gulf/Greece
1307	U. S. South Atlantic and Gulf/Turkey
1308	U. S. South Atlantic and Gulf/Syria
1309	U. S. South Atlantic and Gulf/Lebanon
1310	U. S. South Atlantic and Gulf/Israel (Med.)
1311	U. S. South Atlantic and Gulf/Egypt (Med.)
1312	U. S. South Atlantic and Gulf/Libya, Tunisia, Algeria, Morocco
4100 (14-1.00)	U. S. Atlantic (Service 1)/West Africa, Canary Is., Cape Verde Is., and Madeira Is.
4101 (14-1.01)	U. S. Atlantic/Senegal through Ivory Coast
4102 (14-1.02)	U. S. Atlantic/Ghana through Cameroon
4103 (14-1.03)	U. S. Atlantic/Equatorial Guinea through Angola

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Table 7.14 Trade Routes of the U.S.* (continued)

Trade Route Number	1973 Description
4200 (14-2.00)	U. S. Gulf (Service 2)/West Africa, Canary Is., Cape Verde Is., and Madeira Is.
4201 (14-2.01)	U. S. Gulf/Senegal through Ivory Coast
4202 (14-2.02)	U. S. Gulf/Ghana through Cameroon
4203 (14-2.03)	U. S. Gulf/Equatorial Guinea through Angola
4300 (14-3.00)	U. S. Pacific/West Coast Africa, Canary Is., Cape Verde Is., and Madeira Is.
5100 (15-A.00)	U. S. Atlantic/South & East Africa, Malagasy Rep., St. Helena, Ascension Is.
5101 (15-A.01	U. S. Atlantic/Rep. of S. Africa
5102 (15-A.02	U. S. Atlantic/Mozambique
5103 (15-A.03	U. S. Atlantic/Tanzania, Kenya
5104 (15-A.04)	U. S. Atlantic/Malagasy Rep.
5200 (15-B.00)	U. S. Gulf/South & East Africa, Malagasy Rep., St. Helena, Ascension Is.
5201 (15-B.01)	U. S. Gulf/Rep. of S. Africa
5202 (15-B.02)	U. S. Gulf/Mozambique
5203 (15-B.03)	U. S. Gulf/Tanzania, Kenya
5204 (15-B.04)	U. S. Gulf/Malagasy Rep.
5300 (15-0.00)	U. S. Pacific/South & East Africa, Malagasy Republic, St. Helena, Ascension Is.
1600	U. S. Atlantic, Gulf/Australia
1601	U. S. Atlantic, Gulf/Australia
1602	U. S. Atlantic, Gulf/New Zealand
1700	U. S. Atlantic, Gulf, and Pacific/Indonesia, Malaysia, Singapore
1701	U. S. Atlantic/Indonesia
1702	U. S. Gulf/Indonesia
1703	U. S. Pacific/Indonesia
1704	U. S. Atlantic/Malaysia
1705	U. S. Gulf/Malaysia
1706	U. S. Pacific/Malaysia
1707	U. S. Atlantic/Singapore
1708	U. S. Gulf/Singapore
1709	U. S. Pacific/Singapore
1800	U. S. Atlantic, Gulf/India, Pakistan, Ceylon, Burma, Persian Gulf, Gulf of Aden, Red Sea
1801	U. S. Atlantic, Gulf/India
1802	U. S. Atlantic, Gulf/Pakistan

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Table 7.14 Trade Routes of the U.S.* (continued)

Trade Route Number	1973 Description
1803	U. S. Atlantic, Gulf/Ceylon
1900	U. S. Gulf/Caribbean (Incl. Cristobal), East Coast Mexico
1901	U. S. Gulf/Mexico (East Coast)
1902	U. S. Gulf/Colombia (Carib.)
1903	U. S. Gulf/Venezuela
1904	U. S. Gulf/Netherlands Antilles
2000	U. S. Gulf/East Coast South America
2001	U. S. Gulf/Brazil
2002	U. S. Gulf/Uruguary
2003	U. S. Gulf/Argentina
2100	U. S. Gulf/United Kingdom and Ireland (Eire), Continental Europe North of Portugal
2101	U. S. Gulf/United Kingdom, Ireland (Eire)
2102	U. S. Gulf/Spain (N. of Portugal)
2103	U. S. Gulf/France (Atlantic)
2104	U. S. Gulf/Belgium
2105	U. S. Gulf/Netherlands
2106	U. S. Gulf/West Germany (North Sea)
2107	U. S. Gulf/Scandinavia and Baltic
2200	U. S. Gulf/Far East
2201	U. S. Gulf/Japan
2202	U. S. Gulf/Rep.of Korea
2203	U. S. Gulf/Okinawa
2204	U. S. Gulf/Taiwan
2205	U. S. Gulf/Hong Kong
2206	U. S. Gulf/Philippines
2207	U. S. Gulf/South Vietnam
2208	U. S. Gulf/Thailand
2300	U. S. Pacific/Caribbean (Incl. Cristobal), East Coast Mexico
2301	U. S. Pacific/Colombia (Carib.)
2302	U. S. Pacific/Venezuela
2400	U. S. Pacific/East Coast South America
2401	U. S. Pacific/Brazil
2402	U. S. Pacific/Uruguay
2403	U. S. Pacific/Argnetina
2500	U. S. Pacific/West Coast South America, Central America and Mexico, Canal Zone (W.C.)

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Table 7.14 Trade Routes of the U.S.* (continued)

Trade Route Number	1973 Description
2900	U. S. Pacific, Hawaii, Alaska/Far East
2901	U. S. Pacific, Hawaii, Alaska/Japan
2902	U. S. Pacific, Hawaii, Alaska/Rep. of Korea
2903	U. S. Pacific, Hawaii, Alaska/Okinawa
2904	U. S. Pacific, Hawaii, Alaska/Taiwan
2905	U. S. Pacific, Hawaii, Alaska/Hong Kong
2906	U. S. Pacific, Hawaii, Alaska/Philippines
2907	U. S. Pacific, Hawaii, Alaska/South Vietnam
2908	U. S. Pacific, Hawaii, Alaska/Thailand
3100	U. S. Gulf/West Coast South America
3101	U. S. Gulf/Colombia (West Coast)
3102	U. S. Gulf/Ecuador
3103	U. S. Gulf/Peru
3104	U. S. Gulf/Chile
3200	U. S. Great Lakes/United Kingdom & Ireland (Eire), Continental Europe North of Portugal
3201	U. S. Great Lakes/United Kingdom and Ireland (Eire)
3202	U. S. Great Lakes/Spain (N. of Portugal)
3203	U. S. Great Lakes/France (Atlantic)
3204	U. S. Great Lakes/Belgium
3205	U. S. Great Lakes/Netherlands
3206	U. S. Great Lakes/West Germany (North Sea)
3207	U. S. Great Lakes/Scandinavia and Baltic
3300	U. S. Great Lakes/Caribbean (Incl. Cristobal), East Coast Mexico
3400	U. S. Great Lakes/Mediterranean, Black Sea, Portugal, Spain (South of Portugal), Morocco
3500	U. S. Atlantic/Great Lakes Canada
3600	U. S. Gulf/Great Lakes Canada
3700	California/Great Lakes Canada
3800	Washington, Oregon/Great Lakes Canada
5400	U. S. Great Lakes/West Africa
5500	U. S. Great Lakes/South and East Africa
5600	U. S. Great Lakes/Red Sea, India Perisan Gulf, Indonesia, Malaya, Singapore
5700	Round-the-World
5800	U. S. Great Lakes/Pacific Canada

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Table 7.14 Trade Routes of the U.S.* (continued)

Trade Route Number	1973 Description
2501	U. S. Pacific/Mexico, W. Coast Central America, Canal Zone (W.C.)
2502	U. S. Pacific/Colombia (West Coast)
2503	U. S. Pacific/Ecuador
2504	U. S. Pacific/Peru
2505	U. S. Pacific/Chile
2600	U. S. Pacific, Hawaii, Alaska/United Kingdom and Ireland (Eire), Continental Europe North of Portugal
2601	U. S. Pacific, Hawaii, Alaska/United Kingdom, Ireland (Eire)
2602	U. S. Pacific, Hawaii, Alaska/Spain (N. of Portugal)
2603	U. S. Pacific, Hawaii, Alaska/France (Atlantic)
2604	U. S. Pacific, Hawaii, Alaska/Belgium
2605	U. S. Pacific, Hawaii, Alaska/Netherlands
2606	U. S. Pacific, Hawaii, Alaska/West Germany North Sea)
2607	U. S. Pacific, Hawaii, Alaska/Scandinavia and Baltic
6500 (26-C.00)	U. S. Pacific,/Mediterranean, Black Sea, Portugal, Spain (South of Portugal), Morocco,,and Azores
6501 (26-C.01)	U. S. Pacific/France (Med.)
6502 (26-C.02)	U. S. Pacific/Spain (S.E. of Portugal & Med.)
6503 (26-C.03)	U. S. Pacific/Portugal
6504 (26-C.04)	U. S. Pacific/Italy
6505 (26-C.05)	U. S. Pacific/Yugoslavia
6506 (26-C.06)	U. S. Pacific/Greece
6507 (26-C.07)	U. S. Pacific/Turkey
6508 (26-C.08)	U. S. Pacific/Syria
6509 (26-C.09)	U. S. Pacific/Lebanon
6510 (26-C.10)	U. S. Pacific/Israel (Med.)
6511 (26-C.11)	U. S. Pacific/Egypt (Med.)
6512 (26-C.12)	U. S. Pacific/Hawaii Tunisia, Algeria, Morocco
2700	U. S. Pacific, Hawaii/Australia
2701	U. S. Pacific, Hawaii/Australia
2702	U. S. Pacific, Hawaii/New Zealand
2800	U. S. Pacific/India, Pakistan, Ceylon, Burma, Persian Gulf, Gulf of Aden, Red Sea
2801	U. S. Pacific/India
2802	U. S. Pacific/Pakistan
2803	U. S. Pacific/Ceylon

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Table 7.14 Trade Routes of the U.S.* (continued)

Trade Route Number	1973 Description
5900	U. S. Great Lakes/Far East
6000	U. S. Great Lakes/Australasia
7100	U. S. Atlantic/West Coast Central America and Mexico
7200	U. S. Gulf/West Coast Central America and Mexico
7700	U. S. Atlantic/Pacific Canal Zone
7800	U. S. Gulf/Pacific Canal Zone
8000	U. S. Great Lakes/West Coast South America, Central America and Mexico
8100	U. S. Atlantic/Atlantic Canada
8200	U. S. Gulf/Atlantic Canada
8300	U. S. Pacific/Atlantic Canada
8400	U. S. Great Lakes/East Coast South America
8500	U. S. Atlantic/Pacific Canada
8600	U. S. Gulf/Pacific Canad a
8700	U. S. Pacific Canada
8900	U. S. Great Lakes/Atlantic Canada
9100	U. S. Rico/Foreign - Virgin Islands/Foreign Hawaii/Foreign (Except T.R. - 2600, 2700, 2900, and their subdivisions)
9300	Alaska/Foreign (Except T.R. - 2600, 2900, and their subdivisions)
6100	U. S. Great Lakes/Great Lakes Canada (TransLakes)

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<u>Essential Trade Routes:</u>

0100 through 4200 (14-2.00)
5100 (15-A.00 & 5200 (15-B.00)
1600 through 2600
2700 through 3400

Note: Trade route subdivisions carry numbers ending in other than 00 (e.g., 0101 U. S. Atlantic/Brazil).

partner, therefore the relative value in dollars of trade with each country is proportional to the volume in tons of trade. The Markov chain discussed in Section 7.1.2 should be used to adjust the commodity composition in a more thorough study.

The shipping demand in million ton miles was estimated by multiplying the trade demand in tons by the distance along the 10 country routes. The distances were taken from <u>Distance Between Ports</u> [82] and the trade data is from FT 155 [147] and FT 455 [88] of the U.S. Bureau of the Census. The results are presented in Table 7.16.

Freight rates are assumed by the United Nations to be 5% or 10% of the dollar value of good shipped when it imputes an import value for some country from the exports of reporting countries. Using U.S. Census Bureau data and comparing U.S. import with the corresponding exports of the country from whence they originated, Young [7,p.61] estimates this figure to be an average of 6%. This figure of 6% was used for all commodity values to get the freight rates. Figures presented in the case study result above indicate maximum potential gain relative to the cost of operating are approximately 2%. Assuming the capture of 50% of the maximum, we get the total annual benefit shown in

Table 7.15 Trade Estimates and Route Distances

	(Trade in 000 long tons) Import Estimates			Export Estimates			(Exports + Imports) Total Trade			(in 000's of nautical miles) Distance
	1987	1992	1997	1987	1992	1997	1987	1992	1997	
United Kingdom	8,357	8,855	8,924	27,056	30,630	34,422	35,613	39,485	43,346	2.957
West Germany	13,905	15,349	16,554	41,652	46,541	52,074	55,557	61,896	68,628	3.772
France	12,836	14,759	17,072	14,952	16,707	18,093	27,788	31,466	35,165	3.054
The Netherlands	14,975	17,711	20,693	49,128	55,293	61,783	64,103	73,004	82,476	3.438
Ireland	2,139	2,952	3,880	1,068	1,193	1,324	3,207	4,145	5,204	2.959
Belgium Luxembourg	10,697	12,397	14,227	19,580	22,276	24,713	30,277	34,673	38,940	3.357
Sweden	2,353	2,598	2,975	2,492	2,785	3,089	4,845	5,383	6,064	4.187
Denmark	1,604	2,125	2,716	2,848	3,182	3,972	4,452	5,307	6,688	3.846
Japan	47,065	54,313	60,785	184,406	204,464	225,065	231,471	258,777	285,850	4.839
Taiwan	5,348	7,084	9,182	11,392	14,320	16,770	16,740	21,404	25,952	5.611
	119,479	138,143	157,008	354,574	397,341	441,305	474,053	535,534	598,313	

Table 7.17. The figure of 50% capture is qualitative and its basis was explained in Section 7.4.4 in the context of the Alaskan marine operation.

The case study results were inconclusive with regard to ship routing for oil tankers. The same capture potential was, nevertheless, assumed to be valid for tankers as well as for non tankers. Tankers play a less significant role on the trade routes explained than in the rest of world trade as the following figures show:

U.S. Trade Data With 10 Partners

(000$)	(000$)	(000lbs)	(000lbs)	
I	E	I	E	
$ 80,536 (0.4%)	$ 709,722 (6.4%)	8,364,943 (13.1%)	72,206,702 (32.4%)	Fuel
$17,893,952 (100%)	$11,065,054 (100%)	63,878,4325 (100%)	223,190,143 (100%)	Total

Table 7.16 Generalization of Study Results, Ocean Routing

		Estimates		
Total Trade (000's) tons	1972	1987	1992	1997
a. 10 U.S. partners in this study	290,025	474,083	535,534	598,313
b. World	2,780,000			
Shipping Demand (in thousand million ton miles)				
a. 10 U.S. partners in this study	1,214	1,983	2,241	2,504
b. World*	12,970			

Table 7.17 Benefits to Optimum Ship Routing (in $ millions)				
	1987	1992	1997	1985-2000
Case Study Generalization	$33.7	$38.1	$42.5	$577.5

7.1.5 Extended Econometric Model of Shipping Supply and Demand

The econometric model outlined in section 7.1.2 and 7.1.3 has been partially implemented in this study. While completion of the model would be an improvement in both the accuracy of the results and the understanding of structural elements behind the results, it still leaves out of the analysis much which is usually found relevant in this area. In this section an extended econometric model is proposed to improve the basic model. The work done in Section 7.1.4, the model in 7.1.2 and 7.1.3 and the extended econometric model form a continuum which leads to greater accuracy and understanding.

Econometric models may, in general, be one of four types:

1. Naive, single equation
2. Naive, simultaneous equations
3. Structural, single equation
4. Structural, simultaneous equations

Naive equations seek to explain and predict the behavior of one or more variables by their past behavior. The equation usually involves the variable lagged on itself or time as a variable. They are called "naive" because they do not seek to explain the behavior of the variables in a functional way. That is, they do not explain the economic structure involved. They are only useful for predictive purposes.

However, it should be noted that the term "naive" is not meant to reflect on the quality of the predictive capability of such equations. Naive equations may or may not have less predictive capability than structural equations.

The model may involve one equation or a system of equations which must be fulfilled simultaneously. The model outlined in Section 7.1.2 is an example of a naive, single equation model. The extended model discussed now is a structural, simultaneous equation model.

A model is designed to predict the value of variables within the model called endogenous variables. The number of endogenous variables must be equal to the number of equations in the system of equations. In order to predict the value of the endogenous variable, it is necessary to first statistically estimate the value of the coefficients specified in the equations. Then it is necessary to input to the model the value of the variables which are already known, called exogenous variables.

For examples of the various types of econometric models used in deriving the demand for shipping from the demand for trade see Young [7], A.D. Little [112], Planning Research Corporation [184], Litton System [137], and MARAD, Position Papers [3]. For a more general discussion of econometric trade models see Leamer and Stern [180].

In the model below the following extension of the basic model is presented. Trade along a given route which was presented as a function of time.

$$w_{rt} = a_o + a_1 t^{\beta}$$

is now presented as a function

$$w_{rt} = w_{ijt} = \alpha\, y_i^{\beta 1}\, y_j^{\beta 2}\, n_i^{\beta 3}\, n_j^{\beta 4}\, p_j^{\beta 5}\, p_{ij}^{\beta 6}\, p_{ik}^{\beta 7}$$

where

y = GNP (gross national product) at the destination i or origin j

n = Population at the destination i or origin k

p = Price index or price at the origin j, the relative price of i to j, or the general prices k on all other trade routes.

β's = elasticities (see glossary)

α = scaling factor.

That is, the trade on a given route depends on the economic activity (y) the population (n) and the prices (p) at either end of a route relative to the prices on other routes.

Another extension is the estimation of the change in the transition matrix over time. Our new model becomes

$$X_{rt} = f[A_r(t)]X_{r,t-1}$$

With X_{rt} and A_r as defined in Section 7.1.2, it is possible to obtain a least squares estimate of the changes in the A_r matrix from the model

$$A_{rt} = A_{r,t-1}\, T_r + e_t$$

where

T_r = causative matrix which explains the change in A_r over time

e = the unexplained variation in any year.

Constraining each row in A_r and T_r both to sum to unity gives

$$A_{rt} \; U = U, \text{ and}$$

$$T_r \; U = U$$

where

U = a column vector of units

A least squares estimate of T_r is then obtained by

$$\hat{T}_r = \left(\sum_{t=2}^{T} A'_{r,t-1} \; A_{r,t-1}\right)^{-1} \left(\sum_{t=2}^{T} A'_{r,t-1} \; A_{rt}\right)$$

See Dent [66] for a proof.

For any year t in the future $\hat{A}_{rt}$ is estimated as

$$\hat{A}_{rt} = A_{r1} \; \hat{T}^t$$

and thus

$$\hat{Z}_{rt} = \hat{A}_{rt} \; \hat{Z}_{r,t-1} = \hat{A}_{rt}. \; \hat{A}_{r,t-1} \ldots \hat{A}_{r2} \; A_{r1} \; Z_{r1}$$

On the supply side, the following explanation is given to explain the quantity of shipping ton miles supplied.

$$\hat{g}^5_{rkt} = \hat{\gamma}_o + \hat{\gamma}_1 \; f_{rkt} + \hat{\gamma}_2 \; f_{rk,t-1} + \hat{\gamma} f_{rk,t-2}$$

That is, the shipping supply depends on the present and past freight rates. And finally, given the identity

$$\hat{Q}^D_t = \hat{Q}_t \quad S_1$$

as defined in Section 7.1.2 we can derive the freight rate in any time period by solving each

$$\hat{q}^D_{rkt} = \hat{q}^S_{rkt}$$

to get

$$\hat{f}_{rkt} = \frac{\hat{q}^{D}_{rkt} - \hat{\gamma}_o - \hat{\gamma}_2 f_{rk,t-1} - \hat{\gamma}_3 f_{rk,t-2} \ldots}{\hat{\gamma}_1}$$

The remainder of the model is as defined in Section 7.1.2 and 7.1.3.

In order to present the extended and basic models as a unity, the equations, from the operational, rather than the model, point of view are presented side by side in summary form in the Section 7.1.6.

7.1.6 Summary of Operational Equations

EXTENDED ECONOMETRIC MODEL	COMPLETED ECONOMETRIC MODEL
1. Demand for Shipping	
$\sum_{r=1}^{R} x_{rkt} \equiv w_{kt}$ from X_t	Same
$\sum_{k=1}^{K} x_{rkt} \equiv w_{rt}$ from X_t	Same
$w_{rt} = w_{ijt} = \alpha\, y_i^{\beta 1}\, y_j^{\beta 2}\, n_i^{\beta 3}\, n_j^{\beta 4}\, p_j^{\beta 5}\, p_{ij}^{\beta 6}\, p_{ih}^{\beta 7}$	$w_{rt} = a_o + a_1 t^{\beta}$
$Z_{rt} = [A_r(t)] Z_{r,t-1}$	Omitted
$\hat{T}_r = \left(\sum_{t=2}^{T} A'_{r,t-1} A_{r,t-1} \right)^{-1} \left(\sum_{t=2}^{T} A'_{r,t-1} A_{rt} \right)$	Omitted
$A_{rt} = A_{r1} \hat{T}_r^{t}$	Omitted
$\hat{Z}_{rt} = \hat{A}_{rt} \hat{Z}_{r,t-1} = \hat{A}_{rt} \hat{A}_{r,t-1} \cdots \hat{A}_{r2} A_{r1} Z_{r1}$	Omitted
$\hat{X}_t = W_t \hat{Z}_t$	
$\hat{Q}_t^D = D_r \hat{X}_t$ where D_r has distances on diagonal and zeros off the diagonal	Same

EXTENDED ECONOMETRIC MODEL	COMPLETED ECONOMETRIC MODEL
II. Supply of Shipping	
$\hat{q}^S_{rkt} = \hat{\gamma}_o + \hat{\gamma}_1 f_{rkt} + \hat{\gamma}_2 f_{rk,t-1} + \hat{\gamma}_3 f_{rk,t-2} \cdots\cdots$	Omitted
$\hat{Q}^D_t \equiv \hat{Q}^S_t$ where $\hat{Q}^s_t$ is composed of the $\hat{q}^S_{rkt}$'s	Omitted
III. Price (Freight Rates)	
$\hat{f}_{rkt} = \dfrac{\hat{q}^D_{rkt} - \hat{\gamma}_o - \hat{\gamma}_2 f_{rk,t-1} - \hat{\gamma}_3 f'_{rk,t-2} \cdots\cdots}{\hat{\gamma}_1}$	f_{rkt} known
IV. Benefits of Satellite Information	
$\hat{\delta}_{rt} = \hat{c}_r - d_{r/}t$	δ known
$\hat{s}_{rt} = (1 - \hat{\delta}_{rt})$	Same
$C\ (I)_t = \sum_{r=1}^{R} \sum_{k=1}^{K} f_{rkt} \times \hat{q}^D_{rkt}$	
$C\ (II)_t = \sum_{r=1}^{R} \sum_{k=1}^{K} f_{rkt} \times \hat{q}^D_{rkt} \times \hat{s}_{rt}$	Same
$B_t = \left[C\ (II)_t - C\ (I)_t \right]$	Same

EXTENDED ECONOMETRIC MODEL				ECONOMETRIC MODEL
Dimensions				
i - origin	I			
j - destination	J			
r - trade route i to j or j to i	R →	all major world routes	→	10 U.S. routes
k - type commodity	K →	19 commodities	→	10 commodities
h - all other trade areas				
t - year	T			

DEFINITIONS [Note: Capital letters indicate a matrix; the ($\wedge$) figure indicates an estimated value.]

Coefficients

α - scaling factor which equates units on each side of equation.

β - elasticity of exports w (or imports w) to the variable attached.

γ - coefficients relating a unit difference in the independent variable to the change in the dependent variable (except for γ_o which is the shipping supply if no rates are earned, i.e. all f=0)

c - maximum percentage decrease in freight rates which may be captured by use of SEASAT forecasts.

d - coefficient with no significant interpretation.

Variables

x - tons imported or exported, by route by type commodity by year.

w - tons imported or exported, by route by year.

y - GNP (gross national product)

n - population

p - price or price index

q^S - ton miles of shipping supplied, by route by type commodity by year.

q^D - ton miles of shipping demanded, by route by type commodity by year.

f - freight rate in dollars per ton mile, by route by type commodity by year.

δ - percentage decrease in a freight rate which is captured by use of SEASAT forecasts, by route by year.

s - ratio of freight rate without SEASAT forecast to freight rate with SEASAT forecast

Matrices

X - basic trade data matrix composed of x's .

Z - Normalized row vector matrix from X matrix.

A_r - transition matrix for trade route r .

A - transition matrix in general form.

T_r - causative matrix which explains change in A_r over time.

Q^D - basic shipping demand estimates matrix composed of $\hat{q}^D_{rkt}$'s .

Q^S - basic shipping supply estimates matrix composed of $\hat{q}^S_{rkt}$'s .

C - shipping costs matrix (one by one), by route by year.

B - benefits matrix (one by one) in dollars by year.

W - total route flows matrix .

D - matrix of distances .

7.2 Ice Reconnaissance and Arctic Operations

7.2.1 Introduction and Summary

Shipping following the trade routes 5, 7, 8, 9 between the United States East Coast to Northern Europe and trade route 32 between the Great Lakes to Northern Europe must, over a great circle distance of about 240 miles, pass through a region frequently infested with sea ice and icebergs, during the ice season from December to August.

Routes have been defined to the South of the ice zone for maximum shipping safety but the ice field edge is in constant motion so that all shipping requires precise information about ice location during the 240 mile transit, if no transit time delay is to be experienced. Ships have two transit choices without precise information. They can transit the ice field region at reduced speed or they can follow a course further south around the ice regions at normal operating speeds. The former alternative usually requires a one-third speed reduction, the latter alternative an additional 100 miles of steaming. With an average cruising speed of 16 knots, the former alternative results in about 7.5 hours increase in transit time and the latter alternative about 6.25 hours.

Interview information from carriers operating in this area indicates that of the six - eight hours delay associated with the ice region passage, four hours could be saved through information contributed by SEASAT. Further, the frequency with which severe iceberg and sea state conditions occur leads to an estimate that about 50% of the transit traffic would participate in the four delay hours savings.

Cargo rates along these routes are regulated by the North Atlantic Freight Conference. Carriers therefore emphasize customer service, the principal attributes of which are minimum schedule times and a high dependability of meeting them.

The form of benefit visualized in this application is that resulting from the four hour operating cost saving for each applicable ship traversing the ice region during the ice season, a saving that is presumed to be fully integrated into the shipping schedules. The integration requires that the shipping carriers therefore believe that the four hour saving is realizable through the information and its timeliness of its availability, as supplied by SEASAT. This information concerns the certainty of sea ice and iceberg positional distribution and density and their associated weather conditions.

The sea ice and iceberg information is currently provided by the International Ice Patrol (IIP) under the administrative and operational responsibility of the U. S. Coast Guard. The data available to the IIP is provided by

1. visual sightings from IIP patrol aircraft,
2. USCG surface ships operating in the iceberg areas and,
3. commercial ships and planes crossing the North Atlantic, routinely.

Visual sightings are possible only 50 - 60 percent of the time and a computer model is used to forecast location, drift and decay of icebergs. The model uses latest positional data observations supplemented by current, wind and sea temperature observations.

Twice daily facsimile charts and teletype bulletins are issued to shipping on a 1° x 1° latitude, longitude grid showing icebergs and growler sightings. Specific ice information and situational information is also supplied on request. The services are used for route selection and scheduling for transit navigations but generally lack the precision, in both information and updating frequency, to allow schedules to be finely tuned, with dependability. SEASAT's information input will supplement the IIP to allow this fine tuning of schedules if the SEASAT supplied data can be integrated into the operations of the IIP. The requirements for SEASAT capabilities and instrumentation to enable the SEASAT data to be integrated into the operations of the IIP are:

1. SEASAT is an all weather system. Temperature, wind field, wave spectra etc., are provided. This would negate the fog problem. Information reported to ships could be based more on real-time (twice daily) direct observation and on more reliable three - five day leadtime model forecasts. Dependence on extended (up to ten days or longer) forecasts of current iceberg location would, thus be alleviated.

2. Global and continuous coverage of ocean dynamics by a single instrument package could lead to improvement in "iceberg modeling". Forecasts would thus be better where they must be relied upon in practice. This could also eliminate the need for IIP surface ship (oceanographic and patrol cutters) data collection.

3. SEASAT data could be used to direct more refined aircraft monitoring; i.e., SEASAT could identify subregions where aircraft should (presence of icebergs) patrol and should not (absence of icebergs) patrol. Thus, aircraft productivity could be increased.

4. As a corollary to 3 above, the area of coverage could be expanded or frequency increased without undue requirement for additional resources.

5. Once SEASAT data becomes available, three - five years of IIP testing will be required before operational dependence upon such data will be possible.

SEASAT instruments and associated data collection capabilities most appropriate for the Ice Patrol Service are as follows:

1. Synthetic Aperture Imaging Radar (primary) - resolution of 25 m is apparently acceptable, but is marginal for ice patrol purposes. 10 m resolution is preferred. One problem is that of discriminating between fishing boats and icebergs (both constitute navigation problems for merchants shipping in this region). The imaging radar, through measurements of ocean features pertinent to the ice patrol would be useful in decisions on follow-on aircraft surveillance. Daily coverage would be valuable.

2. Radar Altimeter (secondary) - resolution of 10 cm over a ten mile distance would facilitate determination of the Gulf Current (North Atlantic Current) boundary. Given the slope of this current, iceberg movement - shifting from south to east - can be calculated.

3. Scanning Microwave Four Frequency Radiometer (secondary) - 100 km resolution is not sufficiently precise for determination of confluence of Labrador and Gulf Currents and for decay rate (and hence, location/movement) of icebergs. It would require 1 - 10 km resolution.

4. Scanning Microwave Scatterometer - lower wind speed estimation.

Some of this supplementary information may become available through the different SEASAT launchings, but essentially the full benefit can only be assumed when the operational SEASAT is available in 1985. During the SEASAT-A operating period the influence of atmospheric precipitation, including fog on the active instruments must be measured.

7.2.2 Case Study Results

In the introduction, the source of SEASAT benefits from improved ice reconnaissance, was identified as a reasonable four hours reduction in the current six - eight hour variance in the transit time through the ice region along the trade routes between the United States and Northern Europe. It is assumed that this time reduction will be fully integrated into all the maritime operations involved in trade between the United States and Northern Europe. The annual cost saving is then determined by the following formula:

$$\begin{array}{l}\text{Annual}\\\text{Cost}\\\text{Savings}\end{array} = \left(\begin{array}{l}\text{Number of ice}\\\text{region transits}\\\text{during the ice}\\\text{season}\end{array}\right)\left(\begin{array}{l}\text{Hours}\\\text{saved}\\\text{per}\\\text{transit}\end{array}\right)\left(\begin{array}{l}\text{Hourly}\\\text{Operating}\\\text{Cost}\end{array}\right)$$

The number of ice region transits can be subdivided into transits by U.S. shipping and non-U.S. shipping since the IIP maintains these statistics in order to assess the users of the IIP. The cost savings can therefore also be, so subdivided. Table 7.18 indicates the gross benefiting tonnage, by nation, participating in the IIP in 1972. Table 7.18 illustrates the tonnage growth for 1971, 1972, and 1973, an average annual

Table 7.18 Maritime Shipping Expressed in Gross Tons Benefiting from International Ice Patrol	
1971	83,148,000
1972	93,877,000
1973	107,805,000
Source: Office of Maritime Affairs, U. S. Dept. of State	

growth of 14%. The gross tonnages are to be used to define the number of ice region transits by defining a representative gross tonnage per ship, to obtain the number of ships.

An estimate of the average gross tonnage per ship was derived from the data in Table 7.19 as follows. The average gross tonnage per ship, $\overline{GT}$, is estimated to be the weighted sum of the average gross tonnage per ship of each of the member nations, $\overline{GT}_i$; where the weights, P_i, are the respective percentages of the gross benefiting tonnage (as in Table 7.19).

Symbolically,

$$\overline{GT} = \sum (\overline{GT})_i \; P_i$$

where $\overline{GT}$ = average ship gross tons for nation i, as reported in "A Statistical Analysis of the World Merchant Fleets", U. S. Department of Commerce, 1972;

and P_i = percent of benefiting gross tonnage for nation i, as shown in the last column of Table 7.13.

This calculation yields an estimate of approximately 16,500 gross tons per ship.

Table 7.19 Gross Benefiting Tonnage by Nation Participating in the International Ice Patrol Program in 1972

	Gross Tons	Percent
Liberia	16,161,955	17.2
Norway	14,007,331	14.9
U. K.	13,563,172	14.4
West Germany	7,109,159	7.6
U. S.	6,133,226	6.5
Greece	5,844,363	6.2
Italy	5,340,360	5.7
Sweden	2,512,742	2.7
Denmark	2,093,428	2.2
Spain	1,977,232	2.1
France	1,880,670	2.0
Belgium	1,559,108	1.7
Finland	1,313,601	1.4
Netherlands	1,292,362	1.4
Panama	1,250,582	1.3
Japan	1,711,159	1.8
Canada	1,075,819	1.1
Yugoslavia	856,476	0.9
Israel	780,826	0.8
Other*	7,413,851	7.9
Total	93,877,422	100.0

*Contributing gross tonnage carried by non-member nations

Source: United States Coast Guard International Ice Patrol Statistics

An alternative estimate of average gross tons per ship was made based on the distribution of oceanborne commerce by vessel type on trade routes 5, 7, 8, 9 and 32 as shown in Tables 7.20 and 7.21. To obtain the desired estimate, these statistics have been translated into a fleet mix based on an alternate ship classification as shown in Table 7.22. Oceanborne commerce (bottom row) is partitioned into ship classes liners, non-liners, and tankers. The mix, of combination ships, freighters, bulk carriers, and tankers is obtained from the percent distribution of cargo and the correspondence between the two ship classifications. In so doing, it has been assumed that liners operating on trade routes of interest are comprised of 75% combination ships and 25% freighters. Also, it is assumed that non-liners are evenly divided between freighters and bulk carriers. Calculating average gross tons per ship as before yields an estimate of 16,000 gross tons.

The two estimates of average gross tons per ship, 16,500 and 16,000, respectively, are seen to be in relatively close agreement. The latter has been used in calculating the number of ship trips, N, traversing the Grand Banks region during the "iceberg season".* The resultant estimate is for 1973.

$$N = \frac{107{,}805{,}000 \text{ benefiting gross tons}}{16{,}000 \text{ gross tons per ship}}$$

$$= 6{,}700 \text{ ships per ice season}$$

The hours saved per transit is assumed to be four hours for each. The estimated ship daily operating costs by ship class are given in Table 7.23.

Table 7.20 Commercial Traffic on Trade Routes 5,7,8,9 (North Atlantic) by Year and Vessel Class (Thousands of LOng Tons)

	Liner		Non-Liner		Tanker		
	Inbound	Outbound	Inbound	Outbound	Inbound	Outbound	Total
1966	2448	2367	1115	13,140	924	227	20,221
1967	2573	1989	1205	12,138	1006	336	19,247
1968	3216	1946	1606	11,002	3015	306	21,091
1969	2585	1860	1170	11,683	3983	326	21,607
1970	3105	2479	929	17,450	3315	352	27,630
1971	3273	2007	1255	14,202	2282	306	23,325
1972	3163	2041	1553	14,083	3144	368	24,352

*The iceberg season spans about six months of important activity.

Table 7.21 Commercial Traffic on Trade Route 32 (Great Lakes - North Atlantic) by Vessel Class for 1973. (Thousands of Long Tons)

	Inbound	Outbound	Total
Liner	509	452	961
Non-Liner	2611	5429	8040
Tanker	32	164	196

Source: Office of Maritime Affairs, U.S. Department of State.

Table 7.22 Estimated Fleet Mix by Vessel Class for Traffic Traversing Grand Banks Region

	Average Gross Tons*	Liner	Non-Liner	Tanker	Mix by Vessel type %
Combination Passenger & Cargo	14,000	75	-	-	14
Freighter	6,000	25	50	-	40
Bulk Carrier	22,000	-	50	-	36
Tanker	26,000	-	-	100	11
Cargo Distribution by Vessel Type (%)**					

* Average gross tons per ship based on number of ships and gross tons for member nations as contained in "A Statistical Analysis of the Worlds Merchant Fleet".

** Cargo tonnage percentages are for 1973 as reported by office of Trade Statistics, U.S. Maritime Administration.

These cost estimates are based on "typical" quoted daily rates for ships within each class. In a given instance, substantial deviations from these estimates may be found depending on ship displacement, voyage length, type of port handling, etc. However, as overall average costs, these estimates are reasonable.

To obtain an estimate of daily operating cost averaged over all ship classes, (combination, freighter, bulk carrier, and tanker), a weighted sum of the costs in Table 7.17 was calculated. The estimated proportion of the respective ship classes (Table 7.22) were used as weights. This calculation yielded an average daily operating cost of $9700 or an hourly cost of $404. This hourly cost is for U. S. shipping. To adjust for the international distribution of shipping this value is reduced by 30%. Thus the hourly shipping cost is $283. Hence, the following annual cost saving estimate is calculated.

$$\begin{bmatrix} \text{Annual} \\ \text{Cost} \\ \text{Saving} \end{bmatrix} = \frac{6700}{2} \times 4 \times 283 = \underline{\$3.8 \text{ million}} \quad (1974\$)$$

It is to be noted that the number of transits is estimated from mix of 1972 and 1973 statistics, but the calculated cost savings are assumed to be for 1974.

Table 7.23 Estimated Daily Operating Cost by Class of Ship in 1974 Dollars

Ship Class	Daily Operating Cost
Combination Passenger & Cargo	12,500*
Freighter	8,100
Bulk Carrier	10,300
Tanker	9,400

* Based on 1972 operating cost of $11,200/day for a C-4 class ship, and is consistent with a 1974 daily cost of $13,000 quoted by a liner operator.

7.2.2.1 Sensitivity of the Case Study Results

Estimates of the average gross tonnage per ship were derived as the weighted sum of the average gross tons per ship for each of the 19 member nations. This estimate masks possible variations attributable to the merchant fleet mix (combination ships, freighters, bulk carriers and tankers). To determine possible variation in the estimate of gross tons per ship, and, hence, in number of ship passages traversing the Grand Banks region, reported cargo tonnage on trade routes 5, 7, 8, 9 and 32 has been allocated to two alternative merchant ship mixes as shown in Tables 7.24 and 7.25. As shown in these tables, the first alternative results in approximately 67% of the cargo volume being carried by general purpose freighters. The second alternative in general represents a shift of freighter traffic to bulk carrier traffic.

Table 7.24 Ship Mix Alternative I: Liner and Non-Liner Classified Principally as Freighters

	Percentage Composition of Class of Ship			% of Cargo by
	Liner	Non-Liner	Tanker	Vessel Type**
Combination Passenger & Cargo	25	-	-	4.5
Freighter	75	75	-	66.75
Bulk Carrier	-	25	-	17.75
Tanker	-	-	100	11.0
% of Cargo by Vessel Type*	18	71	11	100.0

* Percent cargo by vessel type based on U.S. Maritime Administration statistics for 1972 on trade routes 5,7,8,9 and 32.

** Estimated percent cargo by vessel type based on (*) and on the correspondence between the two ship classification schemes.

Table 7.25 Ship Mixture Alternative II: Liners Classified Principally as Combination Ships; Non-Liners Classified Principally as Bulk Carriers

	Percentage Composition by Class of Ship Liner	Non-Liner	Tanker	% of Cargo by Vessel Type**
Combination Passenger & Cargo	75	-	-	13.5
Freighter	25	25	-	22.25
Bulk Carrier	-	75	-	53.25
Tanker	-	-	100	11.0
% of Cargo by Vessel Type*	18	71	11	100.0

* Percent cargo by vessel type based on U.S. Maritime Administration statistics for 1972 on trade routes 5,7,8,9 and 32.

** Estimated percent cargo by vessel type based on (*) and on the correspondence between the two ship classification schemes.

Multiplying these cargo percentages by the respective ship class, average gross tonnages for each alternative yields high and low estimates of average gross tons per ship of 18,000 tons and 12,000 tons respectively. These estimates, in turn, yield approximately 6,000 and 9,000 trips traversing the Grand Banks region, respectively.

Possible variations in the remaining factors, change in schedule time, proportion of benefiting voyages and daily operating costs are hypothesized in general correlation with the number of voyages during the iceberg season as follows. First, Alternative I generally involves a preponderance of non-liner class vessels. On the average these vessels are slower than the growing fleet of more modern liners and tankers. Alternative II, represents essentially the reverse situation. Because slower transit time translates into longer times for a given distance, a $\pm$ 25% variation in transit time reduction is assumed for purposes of estimating benefit sensitivity. Likely variations in average daily operating cost are obtained as a direct consequence of the fleet mixes by ship classes for Alternatives I and II. That is, average daily operating costs for Alternatives I and II are estimated by the weighted sum of the ship class operating costs (Table 7.23 using the "percent cargo by vessel type" estimates in Table 7.24 and 7.25 respectively). Finally, a ± 20% variation in the proportion of benefiting voyages is assumed arbitrarily for purposes of determining a plausible range of benefits attributable to improved iceberg 7.26. information.

The average annual benefits associated with the extreme cases based on the above are shown in Table .

As a final note on variations in ice reconnaissance benefits, actual benefits in any given year will differ widely from the average because of the degree of severity of the iceberg problem. Some years may involve hundreds of icebergs in the shipping lanes, while other years may result in essentially iceberg free shipping lanes.

7.2.2.2 Case Study Cost Savings

The case study, based on 1973 shipping tonnage benefiting from the International Ice Patrol; ship operating costs in 1974 dollars, and reasonable estimates of the transit hours saved in passing through the ice regions computed an annual integrated cost savings by the shipping of $3.8 million (1974$).

Applying reasonable estimates of the sensitivity of this computed cost savings to the parameters that define it, a range of annual cost savings was determined to be

$2.1 million (1974$) to $6.9 million (1974$)

Realization of this cost saving depends on a 1985 operational capability satellite, and most critically on the inclusion in the SEASAT instrumentation of an imaging radar having a resolution no greater than 25 m, most effectively 10 m, for iceberg identification. In addition, it has been cited as

Table 7.26 Range of Annual Cost Savings from Improved Iceberg Information (1974)

	Lower Estimate	Expected Estimate	Upper Estimate
Number of Voyages in Iceberg Season	6,000	6,700	9,000
Average Reduction in Schedule Time (hours)	3	4	5
Proportion of Benefitting Voyages (Percent)	40	50	60
Ship Daily Operating* Cost (1974$)	10,000	9,700	8,830
Average Annual* Cost Savings (Millions of 1974 Dollars)	$ 3.0	$ 5.4	$ 9.9

* These costs are reduced by 30% to reflect the international character of the ships transiting the iceberg regions, to define cost savings.

opinion, that proving the utility of integrating SEASAT information into the International Ice Patrol operations may take five years for its complete acceptance. Benefits from the cost savings established will, it is assumed, not begin until 1985. Benefits will then continue to be generated. That is, it is assumed that a SEASAT will always be in operation.

7.2.3 Case Study Generalization

7.2.3.1 Introduction

Generalization of this case study will follow two distinct paths.

One path will expand the scope of the IIP of the operation by determining the expansion of world shipping. The other will employ the SEASAT instrumentation and various techniques for countering the impediment to full economic efficiency of a variety of operations, that results from inadequate knowledge about ice conditions. The majority of the applications require remote sensing devices and data reduction techniques that can identify, measure and monitor ice, icebergs, ice leads, ice ridges, ice cracks, ice age, ice thickness and their general movement and disintegration. Ice is seen as an impediment to many sea and lake operations. It limits the duration of use by shipping of the seas and lakes.

Structures in ice prone sea require specialized design and protection methods to withstand pressures generated by ice formation, decay and drift.

7.2.3.2 Expansion of the Scope of the IIP

To derive the maximum benefits resulting from this application it is necessary to determine the total gross tonnage of shipping benefiting from the ice patrol for each year beyond 1985, $T_{85+\alpha}$, and the operating costs for the shipping for each year in 1974 dollars, $C_{85+\alpha}$. Assuming that the four hour saving will remain constant through time, the cost saving in the year $(85+\alpha)$ can be determined in 1974 dollars as $S_{85+\alpha}$ where

$$S_{85+\alpha} = \frac{T_{85+\alpha}}{T_{73}} \frac{C_{85+\alpha}}{C_{73}} \times 3.8 \qquad \$ \text{ million (1974\$)}$$

where T_{73} and C_{73} are the shipping tonnage and shipping costs in 1974 dollars for the year 1973. The benefit of this cost savings, $B_{85+\alpha}$, is then determined in 1974 by discounting for $(11+\alpha)$ years at a discount rate r%. Hence in millions of 1974 dollars

$$B_{85+\alpha} = \frac{S_{85+\alpha}}{(1+r)^{11+\alpha}} = \frac{1}{(1+r)^{11+\alpha}} \frac{(T_{85+\alpha})(C_{85+\alpha})}{T_{73}C_{73}} \times 3.8$$

The integrated benefit from this application, B, is given in millions of 1974 dollars by

$$B = \sum_{\alpha} B_{85+\alpha} = \sum_{\alpha} \frac{S_{85+\alpha}}{(1+r)^{11+\alpha}} = \frac{S_{14}}{T_{73}C_{73}} \sum_{\alpha} \frac{(T_{85+\alpha})\ (C_{85+\alpha})}{(1+r)^{11+\alpha}}$$

The tonnage, $T_{85+\alpha}$, is developed from an economic forecast of the gross shipping along the routes of the case study. To a certain extent, benefits can be subdivided into national and non national benefits if the national tonnage of the International Ice Patrol is accepted as a representative percentage (see Table 7.19).

7.2.3.2.1 Economic Analysis and Results

In Section 7.1.4, which treats optimum ship routine, the export and import trade tonnage between the United States and the rest of the world is projected by two expressions which are only function of time. These functions are

Import function $M = 49017 + 3005.9\ t^{1.053}$

Export function $E = 188047 + 7520\ \ t^{1.034}$

from which the following tabulation can be developed

Year	$\hat{M}$	$\hat{E}$	$\hat{\text{Total}}$	Index
1974	72,344	244,288	316,632	100
1985	112,080	337,385	449,465	141.9
2000	176,039	485,066	661,105	208.8

which estimates the import-export trade growth and defines a growth index relative to 1974 as a function of time.

Assuming that this international growth is uniform with all regions, in particular with Northern Europe, and that the representative ship size remains constant at 16,000 gross tons, and that the ice transit time saving remains constant at four hours, the ice reconnaissance cost savings grow with the growth index, as shown below

	Cost Savings $Million (1974$)		
Year	Lower Bound	Expected	Upper Bound
1974	2.1	3.8	6.9
1985	3.0	5.4	9.8
2000	4.4	7.9	14.4

Averaging arithmetically between 1985 and 2000 to define a representative annual cost saving, the expected annual cost saving is $6.7 million (1974$) with a range from $3.7 million (1974$) to $12.1 million (1974$).

7.2.3.3 Cost Savings and Arctic Operations

7.2.3.3.1 Introduction

Cost savings have not been developed in this study for this form of generalization since it has been studied in depth in Canada. Their derivation of cost saving is summarized. The full report is in Appendix C.

7.2.3.3.2 Canadian Studies Summary

An area of increasing commercial shipping interest is the Great Lakes - St. Lawrence Seaway region. Every winter, navigation on the Great Lakes is suspended for about four months because of ice conditions. This forces the end users of the shipping service to engage in expensive stock-piling and/or to pay expensive ground transportation rates to move cargo during the winter period. Also, seasonal loss of jobs and under-utilization of costly equipment and facilities pose additional economic problems.

Recognizing these problems, Congress authorized a feasibility study in 1965 of the practicability, means, and economic justification for extending the navigation season on the Great Lakes and the St. Lawrence Seaway. Based upon the favorable findings and recommendations of this initial study, a more extensive three-year (6.5 million dollar) program involving ten federal agencies was established in FY 1972 for investigating and demonstrating the practicability of year-around navigation.

A recent and detailed Canadian study titled "Economic Benefits of Sea Ice Remote Sensing Systems" determines the gross benefits of sea ice monitoring for Arctic and St. Lawrence shipping and resource exploration activities. An aggregate benefit of approximately $100 million/year is estimated by 1990 assuming that a system including a Canadian resource satellite, optimized for Arctic ice and ocean surveillance, is available. Table 7.27 summarizes the individually estimated gross annual benefits for

1. Arctic surveys,
2. Arctic shipping,
3. Arctic offshore drilling and production, and
4. St. Lawrence shipping

The report not only estimates the aggregate benefits achievable for various time frames and ice-monitoring system combinations (including satellites), but also provides examples where satellite data (ERTS-1 and meteorological satellite) did or could have provided ice condition data. For example, the report notes that a commercial seismic survey company was using ERTS images in

Table 7.27 Canadian Estimates of Gross Benefits of an Operational Sea Ice Monitoring System

Source of Benefits	Basis of Benefit	Estimated Average Annual Gross Benefit (in millions of dollars)	
1. Arctic Seismic Surveys			
Marine Surveys	7 days/ship season savings 21 ship-season over next 7 years at $100,000 ship day	1.0	(1974-1980)
On-Ice Surveys	Survey production increase 720 line-miles/year at $4,000 line-mile	2.5	(1974-1980)
2. Arctic Shipping			
Summer Only	Production increase ship-days/ship season		
	13-15 at $4,000/ship day .06/ship	8-9	1974 level of 150 ships
		21-24	1980 level of 400 ships
Year-round	Fleet reduction, travel time reduction, and insurance rate reduction	2.2	Ore
		41-76	Oil by 1990
	(1 ship in 8 reduction, 1 day/shipload savings, and 10 percent insurance rate reduction)	21	Gas
3. Arctic Off-Shore Drilling and Production			
Design, Operation, and Site Selection	Drilling days saved $90,000/day west coast $50,000/day east coast 2-day savings/well	1-3.4	(5 wells by 1977-19 by 1980)
4. St. Lawrence Shipping			
Ice Movement	Savings in transit time 6 hr/ship 3,000 ship movements $8,000/ship day	6	(Based on 1973-1974 season)
Ice Thickness	6 hr/ship same criteria	6	(Based on 1973-1974 season)
Aggregate Benefits Assuming Availability of Effective Aircraft/Satellite Ice Monitoring System by 1990			100/year*

* Estimated Accuracy ± 50 percent.

the summer of 1973 as the tactical navigation aid for the ship they were operating in the northern Arctic. Information from a single ERTS image made it possible for the ship operating in the Norwegian Bay to survey an area that it would otherwise have missed. The image showed the presence of open water beyond a large ice flow, and a path to the open water that permitted an additional one-day survey output of 75 line-miles. Further examination showed that the ERTS data could have made available two or three more days of productive time. The report notes further that based on expert opinions of commercial operators, Arctic navigators, and remote sensing specialists, marine survey ships could save an average of four days per ship season of lost time if they could receive faster transmissions of ERTS and NOAA data from the Canadian station located at Prince Albert.

Other pertinent and recent cost-benefit studies address the dollar benefits associated with extending the navigation season on the Great Lakes. Inherent in this extension is the development of operational ice monitoring and forecast systems (aircraft and/or satellite) capable of supporting shipping operations during part or all of the winter season. Especially noteworthy in this connection is the recently completed (but not publicly available) interim report titled "Great Lakes - St. Lawrence Seaway Navigation Season Extension Survey" for presentation to Congress in July, which contains an extensive cost-benefit analysis.

7.2.3.3.2.1 Arctic Activities (including Alaska)

Shipping and off-shore activities are dramatically increasing in the Arctic. There is a need for reliable ice information for both safety and economic reasons, such as routine shipping operations for resupplying Arctic settlements and bases and specialized shipping in support of increasing Arctic resources exploration and production efforts. The latter involves the operation of seismic survey ships; design and operation of off-shore ports and drilling operations; (including underwater pipelines such as in the

Beaufort Sea) and increasing oil and mineral transport activities. Some 150 vessels operating in the Eastern and Western Arctic areas are small, 2,000 - 10,000 ton class ships whose efficiency is drastically dependent on ice conditions. Such ships are expected to increase three-fold by 1980. Thus it is anticipated that sea ice information requirements for this user group will escalate rapidly as the trend to exploit the natural resources of the Arctic continues and they may eventually become the major user group of improved ice surveillance services.

7.2.3.3.2.2 Scientific/Other Applications

Other activities, in addition to the potential operational users, have requirements for sea ice information. For example, ice damage to coastal installations such as harbors is a major coastal zone expense and management problem. Better ice information and forecasts in combination with improved protection techniques could benefit states and countries prone to coastal zone ice damage. Perhaps not of explicit economic benefit, but certainly of potential practical importance are the scientific advancements that are possible in the disciplines of oceanography, glaciology, meteorology, hydrology, and climatology through better ice information especially in remote areas.

One research area of potential operational benefit, additional fresh water resources by locating and harvesting icebergs, will require continuous global ice monitoring. More extensive understanding of the Antarctic environment including ice conditions have both shipping and scientific significance. However, Antarctic shipping is of very specialized nature (resupply of scientific bases for example) and involves no regular trade routes. Thus, although ice data would be of operational value, shipping is insufficient to economically justify an independent ice monitoring program.

7.2.4 Generalization Summary

Cost savings from expanding the scope of the IIP range from \$3.7 million (1974\$) to \$12.1 million (1974\$) with an expected annual cost saving of \$6.7 million (1974\$).

Summarizing the benefits of ice reconnaissance to Canadian Arctic operations (and excluding those benefits associated with Arctic off-shore drilling and production of oil and natural gas), the Canadian benefits may be stated as:

Time Period	Annual Benefit Range \$Million (1974\$)
1985 - 1989	30.6 to 52.4
1990 - 2000	96.4 to 134.2

7.3 Port and Harbor Operations

7.3.1 Introduction and Summary

7.3.1.1 Introduction

This case study sought to identify those operations in ports and harbors whose efficiency could be quantifiably improved by incorporation of SEASAT operational information. The general nature of the investigation is devoted to determining how shipping harbor and port operational costs are influenced by delays attributable to lack of precision in the estimated time of arrival (ETA) of a ship at the port. An imprecise ETA was assumed to effect ship berthing, unloading of the ship's cargo and ship replenishment all of which must be contracted for ahead of time. Precision in ETA can, it is conjectured, reduce ineffective expenditures in these operations, arising from penalties in these contracts explicit or implicit. Additionally, the investigation sought to identify those areas of dockside activity, such as the loading and off loading of cargo, that may be impacted by inaccurate forecasts of local weather conditions.

The major operations are ship scheduling, port operations and terminal operations, each operation being made up of many functions.

The operations of each port and harbor are specialized to its particularized characteristics. The case study investigated two fair weather ports in the U.S.; San Pedro and Long Beach; three foul weather ports in the U.S.; New Orleans, New York, and those associated with the Columbia River Bar; and outside ports (off shore terminals) in the U.S., primarily used by tankers. Any advantage that SEASAT can produce must be incorporated into the structure of the operations at the port to be useful.

7.3.1.2 Summary

The study, after careful investigation of the port operating mechanisms concluded that the expectation of cost savings, from ETA improvement, at the ports scrutinized was very small. The economic benefits to port and harbor operations from ETA improvement was therefore estimated to be zero and the study was then terminated. Consequently, generalization of the case study was not conducted.

During the course of this study it became evident that opinion concerning possible benefits from ETA improvement is divided amongst those responsible for port and harbor operations. The opinions are qualitative and no quantitative data or statistics have emerged that could or could not support the opinions offered. It is not clear whether or not mechanisms exist at ports to construct such statistics.

The practical solution has been to adapt operations to the judgmental statistics of experience. It would seem reasonable to assume that if an ETA improvement can be provided with confidence to the operations, then adaptation of the operations would occur and hence produce benefits.

Contact with port and harbor controllers and managers has disclosed that local weather predictions, of rain or fog conditions, can also produce operational cost savings. Again, no statistics of such weather events appear in the individual ship's logs or the accounting of shipping lines. It is expected that the weather and sea condition predictions could be provided by an operational SEASAT and that benefits would then be possible, although their quantification may require considerable data collection.

Similar remarks, concerning the influence of weather, on mooring of tankers at outside ports, can be made, as a result of fog or agitated sea conditions at the mooring site. Since this form of tanker operation is comparatively recent, no statistics are available. Future capabilities of the SEASAT operational system could alleviate some or all of these associated unloading delays if localized weather conditions could be predicted.

It is our conclusion that the operation of ports and harbors should receive further study. The analysis of further effort should aim at quantifying the effect of ocean conditions on missed ETA's and the prediction of local weather conditions on the economy of dockside operations. This will entail working through shipping companies to obtain statistics on missed ETA's and/or longshoreman's idle time as a result of inaccurate weather forecasts. With these statistics it will then be possible to treat the subject of ports, harbors, and dockside operations in a quantitative manner.

7.3.2 Case Study Results

7.3.2.1 Introduction

For the port operations study of the influence of weather and sea state forecasts, Table 7.28 was developed as a condensation of suggested savings to ports. This was compiled from references 2 through 5, from the results of two visits to San Pedro (Los Angeles Harbor - References 6 and 7) and from a visit to Long Beach Harbor by Dr. Alden Loomis of JPL. Table 7.28 lists the three major port applications; i.e., ship scheduling, port operations, and terminal operations. It lists all suggested functions under each of the three applications; those functions which can be aided by communications, or ocean/wave (OW) forecasting are marked by an "X", and the company types or agencies affected by these two capabilities for each function are indicated by a dot. The port or harbor is represented by the city and its supporting administrative agencies, including pilots. The terminals are leased by the city to various berthing, ship servicing storage sheds, and marine oil contractors. The shipping lines own the serviced vessels. The shippers are all forwarders of vessel cargo The unions supply all longshoremen. The transportation companies include all land, truck and rail transfer and shipment of goods. Thus, for any port the table is useful in identifying port operations and the agencies concerned with those operations.

During the development of this table the identification was made of the shipping lines as the principals most concerned with harbor and port operations, and not the harbors (the city) or marine terminal operators as previously supposed. The shipping lines have an organization at each port which integrates the interests and requirements of the various lines,

Table 7.28 SEASAT Port Facilities Impact

Area/Subarea - Items	Capability		Affected					
	Comm.	O/W Forecast	Harbor	Termi-nals	Ship Lines	Shippers	Unions	Transp. Co.
1. Ship Scheduling								
(a) Inventory control and reporting	X							
• surplus/shortage knowledge on vessel					●	●		
• status on containerized vessels?					●	●		
(b) Scheduling for maintenance and repairs	X							
• on-board vs. dockside			●		●		●	
• scheduling of shore equipment			●		●		●	
(c) Cargo and freight sales	X	X						
• shipper/forwarder status knowledge of cargo					●	●		●
• new instructions to carrier					●	●		

Table 7.28 SEASAT Port Facilities Impact (Cont'd)

Area/Subarea - Items	Capability		Affected					
	Comm.	O/W Forecast	Harbor	Termi-nals	Ship Lines	Shippers	Unions	Transp. Co.
• rerouting of perishable cargo due to storms					•	•		
• better com-munications regarding								
- manifests					•	•		
- cargo plans				•	•	•	•	
- dock receipts			•	•	•			
- hatch and tank lists				•	•			
- temperature readings/ ventilation records					•			
- notices of readiness to load or discharge (off-shore moorings)			•	•	•			•
- exception reports			•	•	•	•	•	•
- dangerous cargo manifests			•	•	•	•	•	•

Table 7.28 SEASAT Port Facilities Impact (Cont'd)

Area/Subarea - Items	Capability		Affected					
	Comm.	O/W Forecast	Harbor	Termi-nals	Ship Lines	Shippers	Unions	Transp. Co.
- overcarriages and short landing lists			●	●	●			
- interchanges					●	●		
(d) Rerouting due to port conditions	X							
• diversions due to strikes and waiting times			●	●	●	●		
• impact on brokerage exchanges in London, Tokyo, N.Y., Oslo, Baltic, Hong Kong					●	●		
(e) Fuel consumption and bunkering schedule	X	X						
• economical speed alterations for harbor approach					●			
• bunkering instructions predicated on availability and price			●	●	●			

Table 7.28 SEASAT Port Facilities Impact (Cont'd)

Area/Subarea - Items	Capability		Affected					
	Comm.	O/W Forecast	Harbor	Terminals	Ship Lines	Shippers	Unions	Transp. Co.
(f) Vessel documentation and reporting	X	X						
• better communications and ETA for								
- practique and quarantine			•		•			
- clearance and entry (customs)			•		•			
- protest filing					•			
- notices of arrival, readiness, on/off hire					•			
- payroll compilation					•			
- charter party transmission					•			
- dispatch and demurrage statements			•	•	•	•		
- deratization certification					•	•		

Table 7.28 SEASAT Port Facilities Impact (Cont'd)

Area/Subarea - Items	Capability		Affected					
	Comm.	O/W Forecast	Harbor	Terminals	Ship Lines	Shippers	Unions	Transp. Co.
- vessel abstract reporting					●	●		
- port expense reporting					●			
- logbook data transmission					●			
(g) Claims, insurance and legal	X							
• cargo claims and tracing					●	●		
• personal injury cases					●			
• charter party disputes					●			
2. Port Operations								
(a) Personnel requirements	X	X						
• dockside employment, upgrading or elimination?			●	●				
• pilots and tugs			●		●			

Table 7.28 SEASAT Port Facilities Impact (Cont'd)

Area/Subarea - Items	Capability		Affected					
	Comm.	O/W Forecast	Harbor	Terminals	Ship Lines	Shippers	Unions	Transp. Co.
(b) pollution control and marine environment		X						
• collision avoidance in harbors			•		•			
• SEASAT harbor remote sensing			•	•	•			
• fish studies and fish-vessel impact			•					
3. Terminal Operations								
(a) Terminals and stevedores	X	X						
• berth scheduling via ETA accuracy			•	•	•			
• prestow container goods, prestow vessel for loading outbound				•	•		•	
• stevedore labor scheduling				•	•		•	
• notification of consignees and shippers				•	•	•		

Table 7.28 SEASAT Port Facilities Impact (Cont'd)

Area/Subarea - Items	Capability		Affected					
	Comm.	O/W Forecast	Harbor	Termi-nals	Ship Lines	Shippers	Unions	Transp. Co.
• arrange warehouse space				•	•	•	•	
• schedule inland transportation					•	•		•
(b) Inland transportation	X	X						
• scheduling truck operations conforming with ship schedule						•	•	•
• expediting of customs procedures						•		•
• scheduling rail car makeup and car deliveries					•	•	•	•
• tracing of shipments of cargo on through-bills						•		•
• optimization of bookings of "rush" shipments						•		•

Table 7.28 SEASAT Port Facilities Impact (Cont'd)

Area/Subarea - Items	Capability		Affected					
	Comm.	O/W Forecast	Harbor	Terminals	Ship Lines	Shippers	Unions	Transp. Co.
• optimization of leasing and utilization of containers inland				•		•		•
• off-shore mooring for crude oil			•	•	•			•

thus allowing a centralized body to be contacted. Recognizing that centralized representation may disguise individual responses, individual lines were also contacted in this study. Generally, the marine and oil terminals and the unions (stevedores and longshoremen) also have central representation.

7.3.2.2 San Pedro and Long Beach - Fair Weather Ports

Reliable wind and wave forecasts are not very significant to fair weather ports such as San Pedro (Los Angeles) and Long Beach (Ref. 7). All containerized and LASH vessels communicate their ETA's (estimated time of arrival) three days ahead of time to their respective shipping line agents located at the port of arrival, as well as to the Marine Exchange at Lookout Station. The agent is then responsible for arranging berth space, longshoremen, inland transportation, and freight loading. Ships are required by harbor rules to report their ETA, 24 hours in advance in order that the harbor master can schedule pilots. Cancellation of ordered longshoremen crews can be made up to noon the day before arrival if threatening weather or other circumstances might delay ship arrival. Most containerized ships require from 8 to 10 hours to unload and load. Longshoremen begin work at 8:00 a.m. at regular pay of $9 per hour for the first 6 hours then at 1 1/2 overtime. Most vessels attempt to be tied up at the dock by 8 or 9 o'clock a.m. producing a 6:00 a.m. peak on the hourly pilotage demand curves. Other smaller vessels come and go at other hours of the day. Most larger vessels, however, are loaded and back at sea by 7:00 or 8:00 p.m. Captain de Santy, Port Warden of Los Angeles, claims that it is quite rare for a large containerized vessel to appear at midday due to unexpected severe weather not forecast in the 24 hours subsequent to the vessel's last ETA report.

There is no severe demand on the port's services. Vessels are getting larger and fewer (Ref. 6). The proposed radar VTC (vessel traffic control) system (many other ports throughout the world already have VTC) is primarily for collision avoidance. Captain de Santy doesn't see VTC as necessary for queuing control for harbor entrance and berth scheduling since vessel overload is not a problem.

The current procedure for ETA updating during the last three days of a voyage reduces the critical time period of weather influence to the last 18 hours of the voyage, i.e., from noon the day before arrival to 6 a.m. the day of arrival, since then cancellations cannot occur. However, at fair weather ports radical shifts in the weather are very infrequent and an 18 hour prediction would generate only very small improvements.

7.3.2.3 Foul Weather Ports

7.3.2.3.1 New Orleans and New York

New Orleans and New York were selected to represent foul weather ports in the U.S. At these ports, significant entrance swells are reduced by proper seawall design, there is local fog and some degree of channel siltation.

Captain Henry Joffray, Associate Port Director of New Orleans, was contacted. Although he has used Earth Resources Technology Satellite data for siltation origin studies at the mouth of the Mississippi River, he could not see any benefit from SEASAT unless local fogs could be identified with 1 km resolution.

Mr. Clifford B. O'Hara, Director of Port Commerce, and Mr. Alfred Hammond, Superintendent of Development and Planning, were both contacted at the Port Authority of New York and New Jersey. There are always long ship queues waiting to enter New York City, but they are mostly generated by unexpected local fogs and sheer volume of traffic.

A subsequent discussion of operations in North Atlantic ports was held with Captain K.C. Torrens, Operations Manager for Farrell Lines in New York City. Captain Torrens provided a dissenting opinion to the above comments. Captain Torrens stated that ships approaching U.S. North Atlantic ports during the winter can experience large, unanticipated delays during the last 20 hours of crossing. His experience indicated that changes in ocean conditions right up to a few hours before arrival can have major impact on ETA. Captain Torrens stated that the problem was accentuated for ships arriving over weekends, thus necessitating the scheduling of longshoremen crews by noon on Friday for the coming Monday. Further discussion with Captain Torrens indicated that Farrell Lines did not maintain statistics on missed ETA's, thus precluding the possibility of quantifying this problem. Captain Torrens also stated that since longshoremen generally will not work in inclement weather but must be scheduled at least 18 hours in advance, improved accuracy in the forecasting of weather conditions at ports could have a beneficial effect on the costs of loading and unloading operations. For example, according to Captain Sevastio of Moore-McCormack Lines of New York City, there are approximately 10 to 12 occurrences per year when longshoreman crews are hired and then do not work because of inclement weather. Under these circumstances the shipper is obligated to pay the crew for four hours. In the case of break-bulk cargo (typical of Farrell and Moore-McCormack operations) ten gangs of ten to twelve men each may be required to offload one ship. In addition to the longshoremen, dockside support personnel are also required for the offloading. Thus, it is estimated that approximately $10,000 of unnecessary expenses are incurred each time a longshoreman crew is scheduled and then idled by inclement weather. Considering only Moore-McCormack operations in New York City, the unnecessary expenditures for offloading crews due to weather uncertainty would appear to amount to more than $100,000 per year. Further generalization of this benefit would require data on other shippers and ports. In order to quantify this area it will be necessary to obtain statistical information on missed ETA's and dockside crew weather induced idle time.

7.3.2.3.2 The Columbia River Bar

Captain Robert O. Elsensohn, President of the Columbia River Par Pilot's Association, claims this to be the meanest harbor entrance on Earth (Ref. 8). Thirty to thirty-five foot seas must be frequently run by ships over the bar in order to reach the Columbia River ports of Astoria, Vancouver, Longview, and Portland. Ships frequently encounter 36-hour delays getting out over the bar. Approaching ships can cancel longshoremen as late as midnight the night before arrival. Longshoremen idle time is significant since seas can easily build up over the bar in the six hours before morning pilotage. The four ports handle 2,000 ships per year. Pilots are frequently sent out on an ebb tide to entering vessels and then spend one or two days on board unable to return. The Columbia River Bar pilots will work in 50 - 60 knot winds and 25-foot seas using a pilot boat made especially for them in Germany.

Captain Elsensohn was very enthusiastic about SEASAT capabilities and all four port managers believed that it would be advantageous to know present weather conditions if no ships were over the bar reporting them. That ship masters would take any alternate courses of action to realize economic gain based on better weather data was doubted by

Mr. Virgil Worden, President of the Portland Steamship Operators Association and General Manager of the Overseas Shipping Company. A formal letter to Mr. Worden was circulated to all staff of the four ports. The letter requested identification of possibilities for economic benefits from better weather data at the four ports, and the response was a general interest in better wave information. Mr. Worden stated categorically that he could not see any economic gain from improved wind and wave date for dockside operations. All shipping line standing orders direct ship masters to proceed directly and as quickly as possible to the Columbia River Bar pilot station, regardless of weather, because of a "first come, first serve" pilot assignment. Captain Haydon, Operations Manager of Matson Lines, stated that missing transfer schedules by hours has serious cost impositions and may mean the loss of freight contracts by missing inland transportation connections. Therefore, the cost strategy is to steam for port at the maximum possible speed.

7.3.2.4 Outside Ports

The "outside" ports were also investigated in this study. Outside ports are offshore mooring points -- mostly employed by VLCC's (very large crude carriers) which are too large, over 200,000 DWT (dead weight tons) to berth in any U.S. port. A VLCC ties up to an offshore mooring, such as one off El Segundo, Huntington Beach, San Diego, New Orleans, in the Bay of Fundy, etc., and offloads its crude oil via flexible hoses to a pipe to onshore refineries. These pipe connections are delicate in rough seas so that connections can be sheared with resulting oil pollution in inland waters. These accidents cause costs resulting from the loss of oil to the refining company, the clean-up, and the court litigation that results from major spills.

7.3.3 Other Applications Investigated

Two further applications of better forecasting were explored. These are possible reduced insurance rates and lower longshoremen handling fees resulting from reductions in cargo damage. Longshoremen charge significantly higher rates for handling damaged cargo -- the rates can be many times higher than the standard rate and depend upon the degree of danger possible from the damage, e.g. jagged edges on broken crates and ruptured chlorine gas tanks. Longshoremen set the rate at which they will handle damaged freight.

It is highly improbable that the SEASAT-derived weather forecast improvements will have any effect in these two-applications* (Ref.8). Containerized cargo damage today is rare, when it does occur it is generally discovered during offloading. It is impossible to ascribe the damage to heavy seas, poor crating procedures, poor seamanship, or combinations of the three. All contacts agreed on these general conclusions:

1. Crating is an established, political procedure. On containerized vessels, the vessels are viewed as conveyor belts for the systematic flow of containers. The packing specifications would probably remain constant for five-foot seas or 100-foot seas -- one simply packs for maximum seas since the crating cost savings for five-foot seas are negligible. Containers are designed for crane hoisting and placement stability on board the vessel. This procedure results in overdesign of the crates as far as rough seas are concerned.

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*An impressive list of shipping agents support this negative assertion including Mr. Harry Reese, Vice President of General Steamship Corporation, Messrs. Anderson and Donald Scellato of American President Lines, and Captain A. D. Haydon, Operations Manager of Matson Navigation Company.

2. With containerized vessels it takes less gangs of longshoremen with fewer men in each than formerly. Where ten gangs of 10 - 12 men each had been required to handle one ship, two smaller gangs are now needed. Therefore, shipping lines prefer to crate with set, standard procedures and bear the risks of occasional damage to cargo with fewer longshoremen handling the cargo at higher rates.

7.4 The Sea Leg of the Trans Alaska Pipeline

7.4.1 Introduction and Case Study Results

Shipment of North Slope Alaskan oil from the Alaskan port of Valdez to west coast ports of the United States requires passage through waters and weather that greatly influence the total time that elapses between loading an empty tanker and having that tanker return empty to Valdez.

Weather influences the TRT by introducing delays in leaving Valdez harbor because of navigational hazards in the channel. Weather also influences the mooring of a tanker for off-loading the oil at the three representative U.S. ports. These ports are Juan de Fuca, Coos Bay and Santa Barbara; 1212, 1452 and 2028 nautical miles respectively from Valdez.

To leave Valdez harbor local winds must be less than forty knots and visibility must be greater than one mile. Mooring for unleading requires winds less than 35 knots, no fog and no heavy seas. These conditions of weather introduce terminal delays in the operation. In transit, weather, heavy seas and fog also produce time delays since then steaming speed must be reduced from its standard value of approximately 16.5 knots per hour. The weather and sea conditions in the

5-7

Gulf of Alaska are quite volatile, so that extremely violent seas can occur rapidly which are capableof severely damaging a tanker in transit.

The operational SEASAT data and the resulting capability to produce accurate 48^+ hour forecasts of global weather and sea conditions will, to some degree, diminish all these influences of weather and sea conditions on the operational efficiency of the tanker fleet that will transport Alaska oil to the U.S. West Coast.

The case study essentially visualizes that the operational SEASAT data will reduce each tanker round trip time by minimizing the time lost due to weather conditions through improved routing and through a centralized scheduling control of the tankers, based on the weather and sea condition forecasts.

The three selected ports and their distances from Valdez are such that, assuming a tanker speed of 16.5 knots, i.e., the tanker speed in a perfectly calm and non-interfering sea, the loaded unimpeded transit times would be 3.06, 3.67 and 5.1 days respectively, or 73.5, 88.0 and 122.9 hours respectively. For an unimpeded return trip under ballast the transit times would be also as quoted above.

Associated with each transit are the following times which are assumed to be fixed irrespective of the tanker tonnage involved viz:

Time to load a 120,000 dwt tanker	9 hours
Time to unload a 120,000 dwt tanker	10 hours
Time to enter and moor at Valdez	4 hours
TOTAL transit associated time	23 hours

Thus, the <u>unimpeded</u> round trip times between Valdez and the three west coast ports would be as shown in Table 7.29.

If it is then assumed that operationally a tanker would be at sea 330 days per year, the remaining 35 days being down time for overhaul, repairs, etc., and that the required oil distribution from Valdez to the three ports is in the ratio 0.15: 0.35: 0.50 (see DOI [30, p. 60], then a weighted average unimpeded number of round trips per annum per tanker, R_u, is calculated as:

$$R_u + \frac{330 \times 24}{(0.15 \times 170) + (0.35 \times 199) + (0.50 \times 269)}$$

i.e. $\underline{R_u = 34.6}$

Thus, R_u is the theoretical maximum number of round trips per operating year that a tanker could accomplish.

To investigate the influence of the weather along these routes, averages were compiled from the historical data from 1946 to 1971. From these data, time delays, as a result of high seas, fog and winds, were introduced using a computer simulation program. The averages over all years and all months produced weather associated delays for the loaded transits to

Table 7.29 Unimpeded Round Trips Between Valdez & West Coast Ports

Port	Loaded Transit Time (hrs)	Ballast Transit Time (hrs)	Associated Time	TRT (hrs)
Juan de Fuca	73.5	73.5	23	170
Coos Bay	88.0	88.0	23	199
Santa Barbara	122.9	122.9	23	269

the three west coast ports of 22.6 hours, 28.2 hours, and 37.7 hours respectively. For an impeded voyage, to simplify the computational procedure and to minimize computational cost, the return trip under ballast was assumed to be 1.1 times the impeded transit time. The ballast trip times are, therefore, 80.9 hours, 96.8 hours and 134.8 hours respectively. The number of round trips that can be achieved in impeded voyages can then be determined as shown in Table 7.30.

The weighted average impeded number of round trips per annum per tanker R_I is then:

$$R_I = \frac{330 \times 24}{(0.15 \times 200) + (0.35 \times 236.0) + (0.50 \times 318.3)}$$

i.e.

$$\underline{R_I = 29.2}$$

The averaged weather for the voyages considered reduces the number of round trips that are theoretically possible on the basis of assumed tanker performance by 5.4 round trips per annum per tanker. This number of round trips is then the basis of benefit to the operation from SEASAT. That is, it is assumed that SEASAT data will be effectively employed to reduce this round trip loss per tanker, per annum through routing and through scheduling.

The routing model assumed in the case study is shown pictorially in Figure 7.5 which illustrates the structure of the concept. Each numbered segment of the figure is

Table 7.30 Number of Impeded Round Trips

Port	Loaded Transit Time (hrs)	Ballast Transit Time (hrs)	Associated Time (hrs)	TRT (hrs)
Juan de Fuca	96.1	80.9	23.0	200.0
Coos Bay	116.2	96.8	23.0	236.0
Santa Barbara	160.2	134.8	23.0	318.0

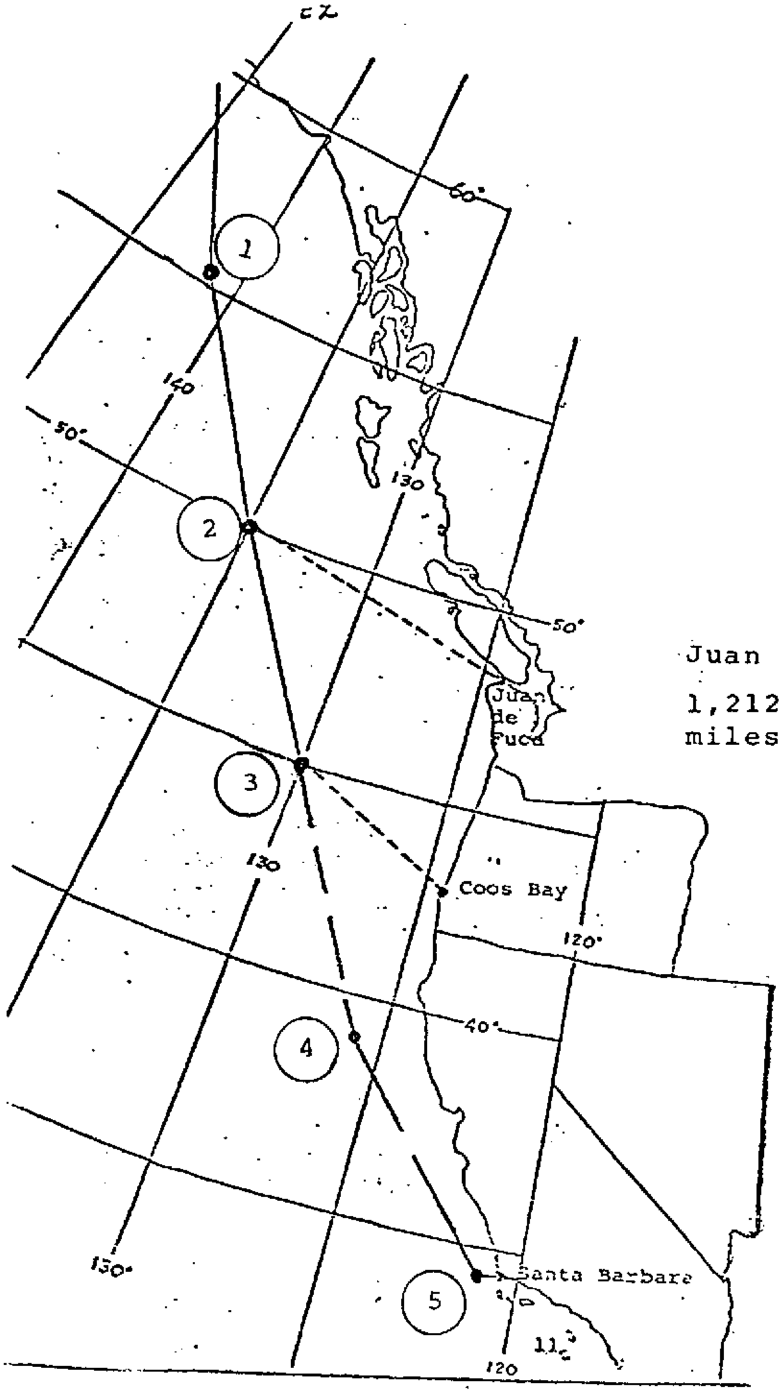
approximately one day transit as are the segments to the indicated ports. Three alternate sea routes are possible from Valdez to point 2 (for the sake of clarity only one of the three possible routes is shown in Figure 7.5). Beyond this point decisions must be made to steam to a clear port based on the weather at the mooring expected when a tanker would arrive. Weather history shows that simultaneous delays at each of the moorings of the three ports is unlikely, so that an optimum choice can be made.

Except to provide the best available navigation equipment, nothing can be done about the navigational hazard in the channel to Valdez harbor.

The source of maximum benefits is the 5.4 round trips per tanker per annum that could be saved if the sea was not an impediment to transit of the tanker fleet. It is estimated that approximately 50% of this theoretical benefit can be realized or captured. Conservatively, it will be assumed that 40% of the maximum or 2.2 round trips per tanker per annum can be captured.

This estimated percentage arises from two sources viz: transit time saving and effective scheduling of the tankers. Occasionally during the historical weather period examined the three ports were simultaneously precluded from unloading while the southernmost port tends to be statistically independent. Effective scheduling appears, however, to be feasible.

The scheduling implies a freedom to direct any tanker to the closest port with appropriate weather which further implies the provisioning of appropriate oil storage at the ports to accommodate the fluctuation in tanker arrival resulting from the scheduling. There is additionally a further implication that the storage and berthing facilities is expected, modify the oil distribution assumed in the weighting of this analysis.



Juan de Fuca

1,212 nautical miles

Coos Bay

1,452 nautical miles

Santa Barbara

2,028 nautical miles

Figure 7.5 Assumed Delivery/Return Track, Valdez to Each of Three Candidate Discharge Points

In summary, in 1985, the time when SEASAT's operational capability can provide the 48^+ hour weather forecasting accuracy requirement, each tanker then operating will be able to achieve 2.2 extra round trips per annum. Provided that differential storage at Valdez and the west coast ports is made available this benefit can be captured.

In addition, the reduced interaction with heavy seas will decrease the hull stresses on every tanker, tending to increase tanker expected life or permitting cheaper tanker design. Further benefits can result from reduced interaction with severe storms in the Gulf of Alaska.

Additional benefits can result from a decreased likelihood of oil spillage during unloading operations or through the reduced possibility of collision by the weather regulation of traffic on this route.

7.4.2 The Model and Summary of Equations

7.4.2.1 Relating the Case Study to the Generalization Model

To quantify the benefits derivable from the applications of SEASAT data to the transportation of oil from the Alaskan port of Valdez to the three West Coast ports a mathematical economic model of the operation was constructed.

The objective of the model was the determination of the minimum transportation cost for a barrel of oil, with a distribution according to the DOI requirement of 0.15:0.35:0.50 to the three West Coast ports. The model was defined by parameters which were in accordance with the investigations of this problem by industry. Differences in certain parameters between the case study and industry occurred. In the model the number of tanker operating days is 345, in the case study 330. In the model the tanker's standard speed is 16.0 knots, in the case study 16.5 knots.

During the development of the model it was learned that the DOI fleet size estimates had been reduced from 41 to 35 ships together with differences in ship size distribution. These changes were embodied in the model.

The modeling sought the minimum transportation cost per barrel of oil through two steps. The first step defined the optimum utilization of the tanker fleet in distributing the oil to the three West Coast ports as required by the DOI distribution of the Valdez output. The optimum utilization is defined in terms of minimum delivery transportation cost per barrel. The problem of utilization is strictly a mathematical one and does not require any SEASAT data. Superimposed on the optimum utilization is the routing benefit provided by SEASAT to reduce the time lost due to inclement weather and sea conditions, and hence to incrementally reduce the per barrel transportation cost.

7.4.2.2 Introduction to the Model

Oil must be carried by tanker from one port of origin in Alaska (Valdez) to three ports of destination on the west coast of the United States (assumed for this study to be the ports of Juan de Fuca at Seattle, Coos Day, Oregon, and Santa Barbara, California) to complete the link between the Northern SLopes field and the U.S. consumers. There will initially be 13 tankers dedicated to delivering this oil. Oil will flow into Valdez from the Northern Slopes at the rate of 1,200,000 barrels per day. Both the number or tankers (13), and the production of oil in Valdez (1,200,000 barrels/day) will be increased in subsequent phases.

There will be storage capacity to serve as buffers in the production and distribution process. The storage tanks will be located at Valdez as well as at the three west coast ports. This marine link is illustrated in Figure 7.6.

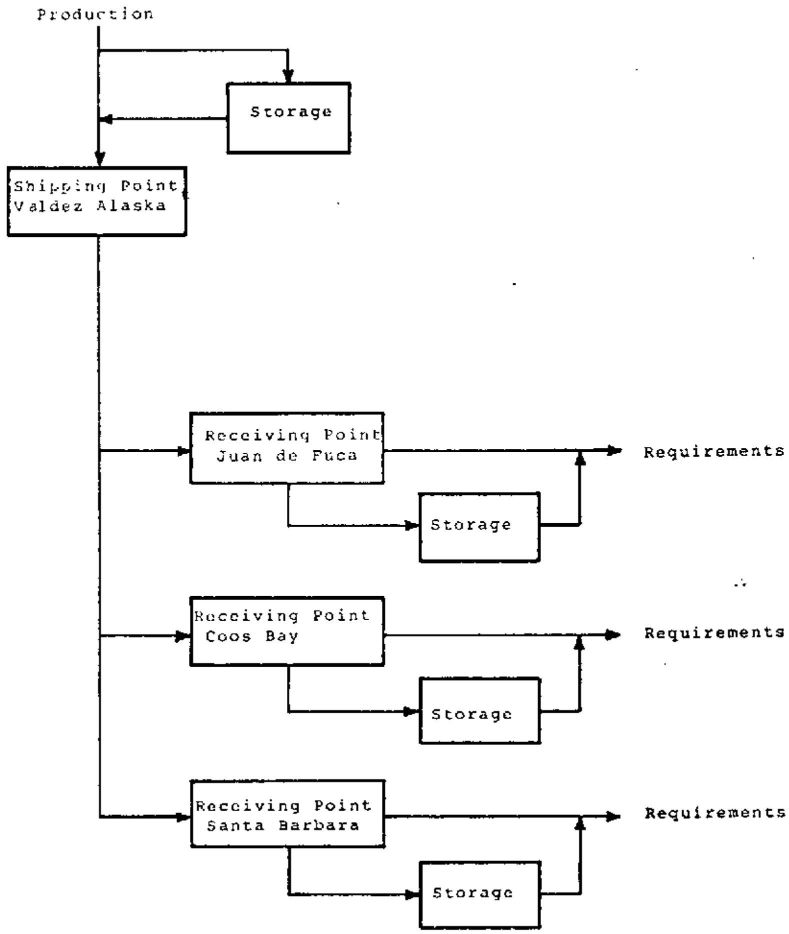


Figure 7.6 Overview of Alaskan Oil Marine Link

Using more timely satellite forecasts may impact on the operation of this link in several ways. An accurate 48^+ hour weather and ocean conditions forecast may prevent a ship from leaving port and sailing into a storm. The tanker can remain in port if the storm is brief and intense or it can sail out and make an immediate diversion to avoid the storm. A ship in stormy weather must cut its speed, sometimew by as much as fifty percent. In addition to the time loss, the probability of damage, loss of life and oil spill, through grounding or collision, increases.

Also, when a ship is at sea, a timely and accurate weather and ocean conditions forecast may permit alternatives in routing that will enable it to by-pass the storm. This maneuver is somewhat limited on the Alaskan run. The basic route hugs the coast and adjustments can only be made by steaming out to sea. There is, thus, little if any time saving by this particular action. But, of course, the weather damage of the storm is still avoided in this instance. In addition to this maneuver, the tanker may also be directed to a more direct route which was stormy if conditions are improving. This gains time and fuel and avoids weather damage. Thus the benefits of routing are threefold. First, it may save time and the operating costs associated with the time saving, principally labor costs. Second, it saves fuel because the tankers spend less time at sea and maintain a more steady and efficient speed during that time. And third, it lessens weather damage.

Besides better weather and ocean conditions forecasts, the oil shipment costs will be affected by the utilization of the various type tankers to the different ports. This is because the tanker types vary in their cost of delivery per barrel and because the ports are not equidistant. It was necessary that any benefits model be able to distinguish between cost savings arising from better weather forecasts or from better utilization.

A mathematical model was developed to permit analysis of the utilization problem and to allow for the impact of better weather and ocean conditions information. By a systematic simulation procedure with the model it was possible to separate the influences of utilization from weather forecasting. The model was kept general enough to apply to any marine transport link system with one origin, multiple destinations, a dedicated fleet of ships of varying capacities, and storage capability at the origin and destinations.

7.4.2.3 The Model

The basic cost parameter on which the model is built is the cost of shipment per barrel. The cost of shipping a barrel of oil depends on the size of the tanker, the time of the year, and the port of destination to which it is to be shipped. This may be expressed as

$$\alpha_{ijk} = a_{ijk}\ \lambda_j$$

where

- a = cost of shipping one barrel of oil ($/barrel)
- λ = the capacity of the tanker (barrels/shipload)
- α = cost of a full tanker delivery ($/shipload)
- i = time period
- j = tanker type
- k = destination

which is the cost of shipping one shipload of oil in period i by tanker type j to destination k.

If satellite information proves beneficial, a percentage decrease in any period i in the cost of shipping a barrel of oil of the magnitude of δ_i should be expected. Multiplying both sides by $(1-\delta_i)$, we get the new cost of a full tanker delivery as

$$(1-\delta_i)\ \alpha_{ijk}$$

Besides this cost of delivering a tanker filled with oil, the marine decision must consider the storage capacity and the associated costs at both ends of the marine link. For example, if costs of shipping are expected to be especially high in the next period due to bad ocean conditions, shipments in that period may be suspended in favor of increased shipments in the present period, increased storage at the destination in the given period and increased shipments in the subsequent run. In general, trade-off can be made amongst shipments, storage at the origin and storage at the destination. For the sake of simplicity it will be assumed that there is no significant oscillation in the storage of oil in a single time period. Storage either increases or decreases linearly in a given period. Further, it is assumed that there is a part of the operating cost of the storage operation which is linearly proportional to the amount of oil in storage. This leads to a cost minimization objective function of the form

$$C = \sum_{i=1}^{t} \sum_{j=1}^{m} \sum_{k=1}^{n} (1-\delta_i)\, \alpha_{ijk}\, X_{ijk} + \sum_{i=1}^{t} \frac{\beta_i}{2} \left(Y_i + Y_{i-1} \right)$$

$$+ \sum_{i=1}^{t} \sum_{k=1}^{n} \frac{\gamma_{ik}}{2} \left(Z_{ik} + Z_{i-1,k} \right) \tag{1.1}$$

where

C = total cost of marine link for period 1 to t (\$/periods 1 to t)

X_{ijk} = number of shiploads in period i of tanker type j shipped to destination k (# of shiploads/period)

Y_i = number of barrels of oil in storage at the end of period i at the origin (barrels)

β_i = cost of storing one barrel over period i at the origin ($ per barrel/period)

γ_{ik} = cost of storing one barrel over period i at destination k ($ per barrel/period)

t = number of period of analysis

m = number of types of tankers classified by capacity

n = number of destinations

subject to all X, Y, and Z $\geq$ 0. It might be noted that X, Y, and Z are not expressed in the same basic unit, i.e., a barrel. Since expressing X in barrels might lead to scheduling of partially loaded tankers, which is not economically feasible by criteria not considered here, the barrel capacity per shipload, λ, was separated from the number of shiploads, X, as indicated above. The same procedure must be observed in the constraints when expressing barrels shipped.

In addition to the non-negativity constraints, there are five sets of constraints to be imposed. These apply to production, requirements, shipping, storage at the origin, and storage at the destination.

The amount produced each period must either be shipped out or added to the storage of the previous period

$$\sum_{j}^{m} \sum_{k}^{n} \lambda_j X_{ijk} + (Y_i - Y_{i-1}) = P_i \text{ for all i}$$

or

$$\sum_{j}^{m} \sum_{k}^{n} \lambda_j X_{ijk} - Y_{i-1} + Y_i = P_i \text{ for all i} \quad (1.2)$$

where

P_i = number of barrels produced in period i (barrels/period)

The amount required at each destination each period must be obtained from what was shipped that period or by drawing down on storage.

$$\sum_{j}^{m} \lambda_j X_{ijk} + Z_{i-1,k} - Z_{ik} = R_{ik} \quad \text{for all } i \quad (1.3)$$

where

R = number of barrels required in period i in destination k (barrels/period)

Another constraint which must be imposed is that the number of trips which can be made by a given fleet is limited, essentially by the finite speed of the ships. Suppose the $\overline{X}_{ijk}$ is the maximum number of trips which can be made by all tankers in class j to destination k in period i, assuming that the tankers experience average delays due to weather. Further, define:

b_{jk} = the number of tankers in class j going to k each period

$\overline{d}_{ik} = \frac{\overline{X}_{ijk}}{b_{jk}}$ the maximum number of trips which can be made in period i by any tanker going to destination k (tankers, regardless of size, find it efficient to maintain a speed of approximately 16 knots).

$b_j = \sum_k b_{jk}$ the total number of ships of type j in the fleet

d_{ik} = the maximum number of trips which can be made by one ship to k with no weather delays in period i.

$\theta_i = 1 - \frac{\overline{d}_{ik}}{d_{ik}}$ the fractional decrease in number of trips possible due to weather delays; assumed independent of destination.

Clearly, then $\frac{X_{ijk}}{\overline{X}_{ijk}} \leq 1.$

But $\bar{X}_{ijk} = b_{jk}\bar{d} = b_{jk}d_{ik}\ (1-\theta_i)$, so that $\frac{X_{ijk}}{d_{ik}} \leq b_{jk}\ (1-\theta_i)$. Summing over all destinations, we find the final form of the constraint:

$$\sum_{k=1}^{n} \frac{X_{ijk}}{d_{ik}} \leq (1-\theta_i)\ b_j \qquad (1.4)$$

For the storage constraint at the origin, we have

$$Y_i \leq S_i \text{ for all } i \qquad (1.5)$$

where

S_i = storage capacity at the origin in period i (barrels/period)

Initial and final yearly constraints are added to these storage constraints

$$Y_o = S_o \text{ and } Y_t = S_t$$

This will add one variable, Y_o, to the objective function.

In analogous manner, the constraints on storage at each destination are:

$$Z_{ik} \leq D_{ik} \text{ for all } i,\ k \qquad (1.6)$$

where

D_{ik} = storage capacity in period i at destination k (barrels/period)

When the initializing constraints are imposed in variables, Z_{ik}, are added to the objective function.

Thus, a linear programming problem which may be solved by the simplex programming method has been formulated. The objective function is, (1.1), with

$$\text{\# of variables} = 1+n+t\ [1+n(1+m)]$$

and five sets of constraints, (1.2), (1.3), (1.4), (1.5), and (1.6) which yield

$$\# \text{ of equations} = 1+n+t\ (2+2n+m)$$

The number of equations is further restricted to be less than the number of variables. This means that:

$$m > \frac{n+1}{n-1}$$

$$\text{or} \quad n > \frac{m+1}{M-1}$$

7.4.2.4 Summary of Equations

The full restatement of the resulting linear programming problem is presented in Tables 7.31 and 7.32.

7.4.3 Use and Economic Interpretation of the Model

The linear programming model discussed in the previous two sections enables us to measure the decreased cost of the Alaskan oil marine link when there is improved utilization of ships and improved weather forecasting. How does this translate into benefits for the consumer? How much of the decrease in cost is due to weather forecasting and how much is due to better utilization? This section answers these questions.

First we must answer the more basic question. What is the value of the Alaskan oil initially? To answer this we look at the supply and demand curves involved. The present world supply and demand for oil without Alaska looks something like Figure 7.7a where S_o^w is the world supply curve and D_o^w is the world demand curve. Before the Alaskan oil is available, the world price is P_o^w and the quantity supplied is q_o^w. We are assuming that the world demand is inelastic and the world

Table 7.31 Summary of Equations
Alaskan Oil Marine Link Model

$$C = \sum_{i=1}^{t} \sum_{j=1}^{m} \sum_{k=1}^{n} (1-\delta_i)\, \alpha_{ijk}\, X_{ijk} + \sum_{i=1}^{t} \frac{\beta_i}{2} (Y_i+Y_{i-1}) + \sum_{i=1}^{t} \sum_{k=1}^{m} \frac{\gamma_{ik}}{2} (Z_{ik}+Z_{i-1,k}) \qquad (1.1)$$

Subject to

production constraints

$$\sum_{j=1}^{m} \sum_{k=1}^{n} \lambda_j X_{ijk} - Y_{i-1} + Y_i = P_i \text{ for all } i \qquad (1.2)$$

requirements constraints

$$\sum_{j=1}^{m} \lambda_j X_{ijk} + Z_{i-1,k} - Z_{ik} = R_{ik} \text{ for all } i, k \qquad (1.3)$$

shipping constraints

$$\sum_{k=1}^{m} \frac{X_{ijk}}{d_{ik}} \leq (1-\theta_i)\, b_j \text{ for all } i, j \qquad (1.4)$$

storage at origin constraints

$$Y_i \leq S_i \text{ for all } i \qquad (1.5)$$

storage at destination constraints

$$Z_{ik} \leq D_{ik} \text{ for all } i, k \qquad (1.6)$$

and

X, Y, Z all ≥ 0

# of equations $\leq$ # of variables.

Table 7.32 Definitions for Equations in Table 7.25

Coefficients

i - time period (t - total number of time periods)

j - tanker type (m - total number of tanker types)

k - destination (M - total number of destinations)

Δ_i - percentage decrease in cost of shipping a barrel of oil in period i (%)

α_{ijk} - cost of a full tanker delivery in period i by tanker type j to destination k ($/shipload)

β_i - cost of storing one barrel at the origin over time period i ($ per barrel/period)

γ_{ik} - cost of storing one barrel at destination k over time period i ($ per barrel/period)

λ_j - the capacity of tanker type j (barrels/shipload)

d_{ik} - the maximum number of trips which can be made in period i by one tanker type j (# of trips)

θ_i - the fractional decrease in number of trips possible due to weather delays in period i (%)

b_j - the number of type j tankers in the fleet. (# of tankers)

Variables

C - total cost of marine link for periods 1 to t ($)

X_{ijk} - number of shiploads in period i delivered by tanker type j to destination k (# of shiploads)

Y_i - number of barrels of oil in storage at the origin at the end of period i (barrels)

Z_{ik} - number of barrels of oil in storage at destination k at the end of period i (barrels)

P_i - number of barrels produced in period i (barrels)

R_{ik} - number of barrels required at destination k in period i (barrels)

S_i - storage capacity at the origin in period i (barrels)

D_{ik} - storage capacity at destination k in period i (barrels) supply is less inelastic as drawn.* (The Hudson-Jorgenson model of oil demand estimates the elasticity of demand for oil to be -.15, while the Erikson-Spann econometric model finds the elasticity of supply for oil to be +.85. See Adelman [34, p. 29 and p. 34, respectively].)

When Alaskan oil becomes available, it will be available at a significantly lower price but not in sufficient quantity to satisfy the U.S. demand. Therefore, the Alaskan oil will be fully consumed and there will be a corresponding shift downward in the world demand curve, as pictured above, to D_1^w. Since the Alaskan oil is earmarked for U.S. markets and since there will be at least implicit price control, two markets will develop, each with its own supply and demand and price. In the world market, exclusive of Alaskan oil, the quantity demanded will drop back by the amount of oil supplied from the Alaskan fields to $q_o^{w'}$. But at this point the available supply exceeds the world demand and there will be some downward pressure on price. This will induce the quantity demanded to increase beyond $q_o^{w'}$ and the dropping price will not draw forth the previous supply of q_o^w. The new equilibrium point will be price p_1^w and quantity q_1^w.

---

* Elasticity is defined as a ratio of percentages: the percentage change in one variable relative to the percentage change in a second variable. For example, the elasticity of the quantity demanded to its price is given symbolically by

$$\varepsilon = \frac{\dfrac{q_1-q_o}{q_o}}{\dfrac{p_1-p_o}{p_o}} = \frac{\dfrac{\Delta q}{q}}{\dfrac{\Delta p}{p}} = \frac{\%\text{ change in quantity demanded}}{\%\text{ change in price}}$$

When $|\varepsilon|<1$, we say the quantity demanded is inelastic, or insensitive, to price changes. When $|\varepsilon|=1$, we say the demand is elastic. And when $|\varepsilon|=1$, we have "unitary" elasticity. Other commonly used elasticities are the elasticity of the quantity supplied to price and the elasticity of the quantity demanded to income. When we speak of simply the demand or supply elasticity, we mean relative to price unless stated otherwise.

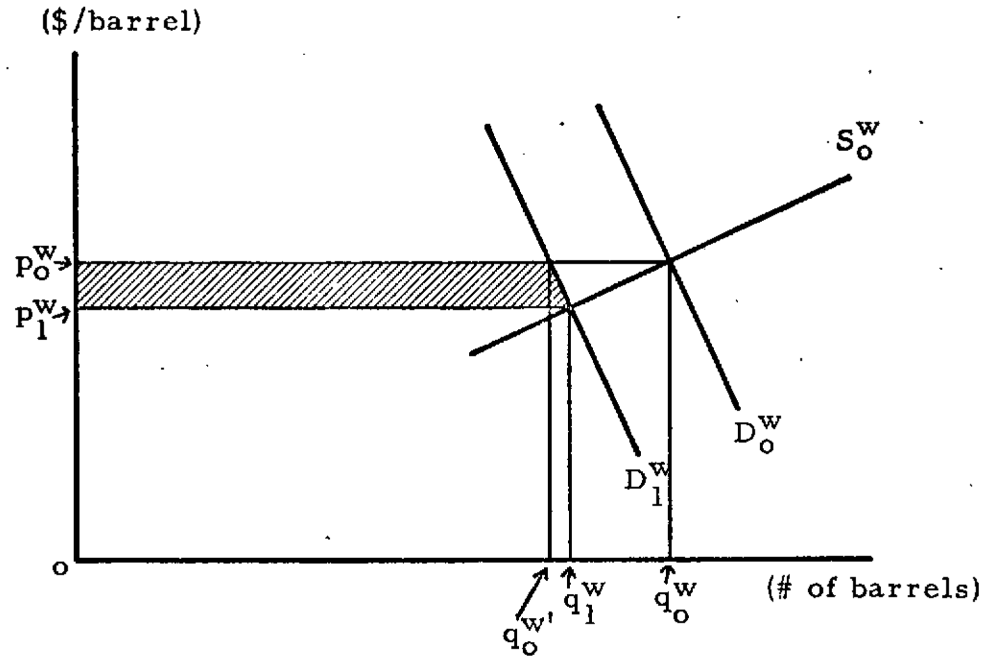


Figure 7.7a World Supply and Demand for Oil

The supply and demand for Alaskan oil can be illustrated as in Figure 7.7b.

Assuming q_a^1 is the maximum amount of Alaskan oil which can be brought into the U.S. market from Alaska each year (i.e., the supply curve becomes vertical at q_a^1), we would find that the demand would be insatiable, i.e., the demand curve would be horizontal as presented.

The consumers were initially consuming quantity q_o^w at price p_o^w. We know

$$q_1^a = q_o^w - q_o^{w'}$$

So, the consumers are obtaining $q_1^w - q_o^{w'}$ extra oil $[q_o^w = q_o^{w'} + q_1^a; < q_o^w \; q_o^{w'} + (q_1^w - q_o^{w'}) + q_1^q]$.

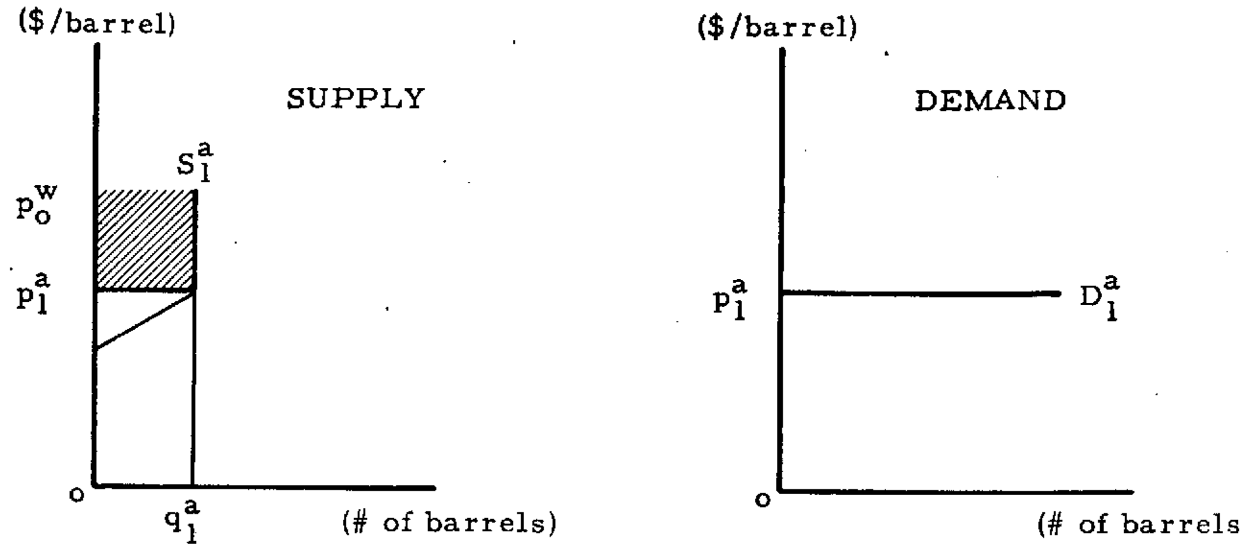


Figure 7.7b Supply and Demand for Alaskan Oil

The consumers are consuming q_1^w and q_1^a at prices p_1^w and p_1^a, respectively.

In conclusion, we see the consumers are paying lower prices and getting more oil.

This benefit is represented by the sum of the shaded areas in the two diagrams above and it has an economic interpretation. It is clearly the extra amount consumers were willing to pay, rather than do without the product. This saving is known as the <u>consumer's surplus</u> (see glossary).

We derive this benefit mathematically as follows:

$$B_1 = q_1^a \times (p_o^w - p_1^a) = \text{A direct benefit}$$

Assuming a linear supply curve and that we know the elasticity of supply, ε_s, and p_o^w, q_o^w, and $q_o^{w'}$ (from $q_1^a = q_o^w - q_o^{w'}$), we have

$$\varepsilon_s = \frac{\dfrac{\Delta p^w}{p_o^w}}{\dfrac{\Delta q_o^w}{q_o^w}} = \frac{\dfrac{p_o^w - p_1^w}{p_o^w}}{\dfrac{q_o^w - q_o^{w'}}{q_o^w}}$$

and we can solve for p_1^w directly

$$p_1^w = p_o^w \left(1 - \frac{q_o^w - q_1^w}{q_o^w} * \varepsilon_s\right)$$

Similarly, assuming a linear demand curve and a knowledge of the elasticity of demand, ε_d, we have

$$\varepsilon_d = \frac{\dfrac{q_o^{w'} - q_1^w}{q_o^{w'}}}{\dfrac{p_o^w - p_1^w}{p_o^w}}$$

and we solve for q_1^w

$$q_1^w = q_o^{w'} \left(1 - \varepsilon_d \frac{p_o^w - p_1^w}{p_o^w}\right)$$

We then have

$$B_2 = (p_o^w - p_1^w) \times q_o^{w'} = \text{A direct benefit}$$

and

$$B_3 = (p_o^w - p_1^w) \times (q_o^w - q_o^{w'}) \times 1/2 \quad = \quad \text{The induced benefit}$$

and finally

$$B = B_1 + B_2 + B_3 = \text{Total benefit of Alaskan oil} = \text{Sum of shaded area}$$

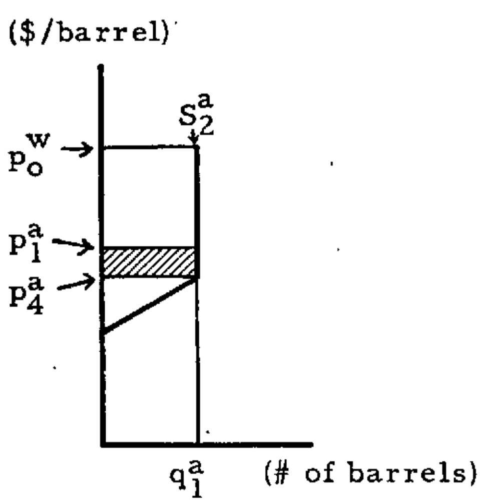
We have completed our discussion of the benefits of Alaskan oil and are now in a position to estimate the impact of weather forecasting. In general, better weather forecasting can be expected to increase B_1 directly, but it will impact on B_2 and B_3 imperceptibly. We will focus on the increase in B_1 and ignore the negligible changes in B_2 and B_3.

There are two outputs from the linear programming model which are of particular importance to us. These are the total cost, C, and the sum of the requirements met in each period i at each port k, $\sum_i \sum_k R_{ik}$. Both of these are a function of how weather forecasting impacts on the percentage change in the cost of shipping a barrel of oil, δ, and the percentage change in the number of trips a given type tanker can achieve, θ. That is

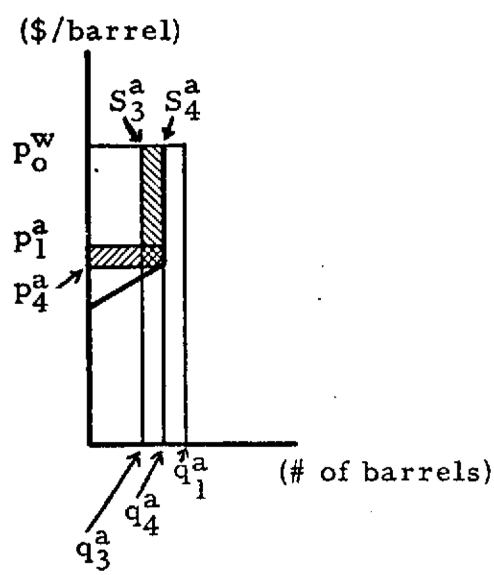
$$\Delta C = f(\delta, \theta)$$
$$\Delta \sum_{ik}\sum R_{ik} = f(\delta, \theta)$$

In regard to the $\sum_{ik}\sum R_{ik}$, we should take note of the fact that the requirements met may be less than what is produced because the shipping capacity is insufficient. In this case, additional oil may be supplied to U.S. consumers by the use of satellite weather information to route the tankers around storms and high seas. When the shipping capacity is already sufficient to deliver the full production of oil, the only benefit to be realized is a decrease in the cost of supplying the oil and the subsequent price to the consumer. We may illustrate these two exhaustive possibilities as in Figure 7.8.

We can see in case a) that the shipping capacity was already sufficient when weather forecasting was introduced, so the only impact is a lower price for the consumer. In case b), we see that the supply curve was at S_3^a and the quantity delivered to the consumer was q_3^a. After weather forecasting is introduced, we move to S_4^a and q_4^w and the benefits of extra oil (the vertical shaded area) is added to the benefit of lower cost.



Case a)



Case b)

Figure 7.8 Benefit of Satellite Information on Alaskan Oil Marine Link

Symbolically, we have

$$q_1^a = \sum_i\sum_k R_{ik} \quad \text{before weather forecasting (barrels); when } \sum_i\sum_k R_{ik} = \sum_i P_i \text{ (Production)}$$

$$q_4^a = \sum_i\sum_k R'_{ik} \quad \text{with weather forecasting (barrels)}$$

$$\Delta C = C' - C$$

where

C - total cost of marine link before weather forecasting ($)

C' - total cost of marine link with weather forecasting ($)

$$p_4^a = p_1^a - \frac{\Delta C}{q_3^a}$$

where

$$q_3^a = \sum_i\sum_k R_{ik} \quad \text{before weather forecasting (barrels); when } \sum_i\sum_k R_{ik} < P_i$$

The benefit of satellite weather forecasting on the Alaskan marine link is then given as

$$B_1 = (p_1^a - p_4^a) \times q_k^a$$

where

$$q_k^a = \min \text{ of } (q_1^a, q_3^a)$$

$$B_1 = (p_o^w - p_4^a) \times (q_4^a - q_3^a)$$

subject to

$$B_1 = 0 \text{ if } q_4^a > q_1^a$$

$$\text{Total Benefit} = \Delta B_1 = B_1' + B_1'' + (p_1^a - p_4^a) \times q_k^a$$

$$+ (p_o^w - p_4^a) \times (q_4^a - q_3^a) \qquad (1.7)$$

The total benefits were calculated using equation (1.7). Since some benefits arose from better utilization of tankers, it was necessary to proceed systematically to isolate the influence of the satellite. (Note: Fixed utilization refers to the utilization scheme for tankers defined by Alyeska for the Department of the Interior [30]. In this scheme, each type tanker visits each port a fixed number of times each year.)

Benefit I, B(I)	-	calculated assuming fixed utilization and no satellite weather forecasting. The baseline case.
Benefit II, B(II)	-	calculated assuming fixed utilization with satellite weather forecasting.
Benefit III, B(III)	-	calculated assuming optimal utilization with no satellite weather forecasting.
Benefit IV, B(IV)	-	calculated assuming optimal utilization with satellite weather forecasting.

The true benefit of satellite weather forecasting is [B(II)-B(I)] if no optimal utilization is to be done. The true benefit of satellite weather forecasting is [B(IV)-B(III)] if optimal utilization will be done.

7.4.4 The Results

The model problem was solved for three annual production levels - 730, 400, and 240 million bbl/yr. (or 2,1.1, 0.66 million bbl/day, respectively) - the projected annual outputs in 1985, 1990, and 1995, Alaskan Oil [196]. However, the analysis was conducted by looking at only one quarter of the year and breaking it into 10 day periods. Using such a time reference was desirable because from an operational point of view similar weather conditions may be considered to come in 5-10 day intervals rather than in month to month intervals. Also, the longer the time period considered, the less significant the fixed amount of storage becomes compared to the number of barrels to be shipped. These levels are based on an assumed total reserve in the North Slope field of 10 billion barrels and are uncertain because of uncertainties both in that total reserve and in the rate of consumption. The study by the Cabinet Task Force on Oil Import Control in Alaskan Oil [196] indicates that the field will be entirely depleted by the year 2000.

The time scale has, of course, shifted since Alaskan Oil [196] was written in 1970. Current indications are that production will begin in 1977 and reach its peak in the early 80's [23]. The production curves in Alaskan Oil [196], therefore, have been shifted by five years.

The fleet composition in DOI [30, p. 60] has been adjusted. Present projections indicate a fleet of 13, 22, and 35 tankers in each of three successive phases. In 1985 the operation will be in phase 3 and the 35 tanker fleet will be broken down as follows:

Wt. class (Kdwts) -	45	60	70	75	80	90	120	130	150
# of tankers	1	3	2	3	2	2	16	5	1

In 1990 and 1995 when production levels will be dropping it was left to the computer program to eliminate the appropriate tankers since it is obvious that the model will consistently use the more efficient larger tankers when possible and will drop off from the solution the smallest tanker when it becomes expendable.

It was assumed that the oil will be shipped to the three ports on the West Coast in the proportions projected by the Alyeska Pipeline Service Company (APSC) as quoted in DOI [30], namely:

15% to Juan de Fuca
35% to Coos Bay
50% to Santa Barbara

100% from Valdez

The possibility of shipping to other points (e.g., Japan, the East Coast via Panama or the North West Passage) was excluded.

Since industry sources indicate storage capacities of six to eight days production are desirable, storage at both the origin and destinations was assumed to be seven times the level of daily throughput.

Valdez - 14 million (100%) = S

and also

Juan de Fuca - 2.1 million (15%) = D_1
Coos Bay - 4.9 million (35%) = D_2
Santa Barbara - 7.0 million (50%) = D_3

Since there are antitrust considerations involved it was necessary to have the oil companies pass their estimates of the number of tankers they would be purchasing through independent auditors who then indicated only the sums for the resulting fleet. This means in terms of this model that optimization was done with respect to the whole fleet while individual oil companies will be optimizing with respect to their portion of the fleet. Thus, the benefit from better fleet utilization will be greater than what might actually be achieved, but the estimate of the extra benefit of satellite ocean condition forecasting information, which is what must be quantitified in this study, will be reasonably accurate.

The relation between shipping costs and vessel sizes taken from Alaskan Oil [196, p. 72] are

Class (dwt)	Cost ($/bbl/$10^3$ miles)
50	.14-.16¢
100	.10-.11
200	.07-.08

Fitting these by a polynomial we get the curve in Figure 7.9. Since these were world tanker prices they must be doubled as recommended in the reference to reflect the fact that only American ships will be used. Also, since these were 1969 prices they must be inflated to 1974 prices. The inflation factor used was 45.6%, derived from the composite index of construct costs in the US Department Commerce's Survey of Current Business (the cost of the tankers construction is more than 50% of all costs as seen in section 5.1).

It was further assumed that the shipping costs would vary from period to period in roughly the same proportion as the average trip time to Juan de Fuca in each month as determined by ODS [30, p. 12]. The costs, therefore, ranged between 5% above and 4% below the yearly average cost. (This is a conservative range since the weather variation in ten day periods will be larger than the average variation from month to month.) The assumption also overcomes the problem of using representative weather figures for the year when the analysis is only done for one quarter of the year.

Since the operating costs of increasing or decreasing the barrels of oil in storage were found to be negligible these were assumed to be zero. While the model could be adapted to addressing the question of the optimum storage capacity investment, this was not done. It was assumed that the industry estimates given were fixed.

For the shipping capacity constraint the 16.0 knots per hour speed of the modal ship in the fleet, the 120 K dwt tanker, was used to calculate round trips. Assuming 345 days running time and 21 days per year for routine maintenance and repair, 23 hours for turnaround time and 1,212 miles to Juan de Fuca, we get as a maximum

$$\frac{345 \times 24}{2\ (1{,}212/16.0) + 23} = 47.45 \text{ round trips per year}$$

or 11.9 round trips per quarter of the year/ship.

It is assumed by the model that the maximum round trips to the other two destinations are less in proportion to the distances (which were 1,452 and 2,028 miles, respectively). The fleet can be expected to make 34.6 round trips maximum per ship over one year using the weighted distance to the three ports according to ODS assumptions. The ODS computer simulation which used tanker weather log data from 1948 to the present and varied the speeds of the tankers in accordance with the weather conditions reported in the log found that the weather simulated delays permitted only 29.2 round trips. However, this 15% loss cannot be fully avoided because there will be bad weather at all points along the route occasionally. Thus the maximum saving possible was assumed conservatively to be 12% (i.e., $\theta = .12$ as an upper bound] or 4.4 round trips.

Following the estimate of Ocean Data Systems, it was assumed that the achievable gain in shipping capacity due to satellite information was 50% ($\theta = .06$) of the total potential capacity gain, i.e., 2.2 round trips saving was used.

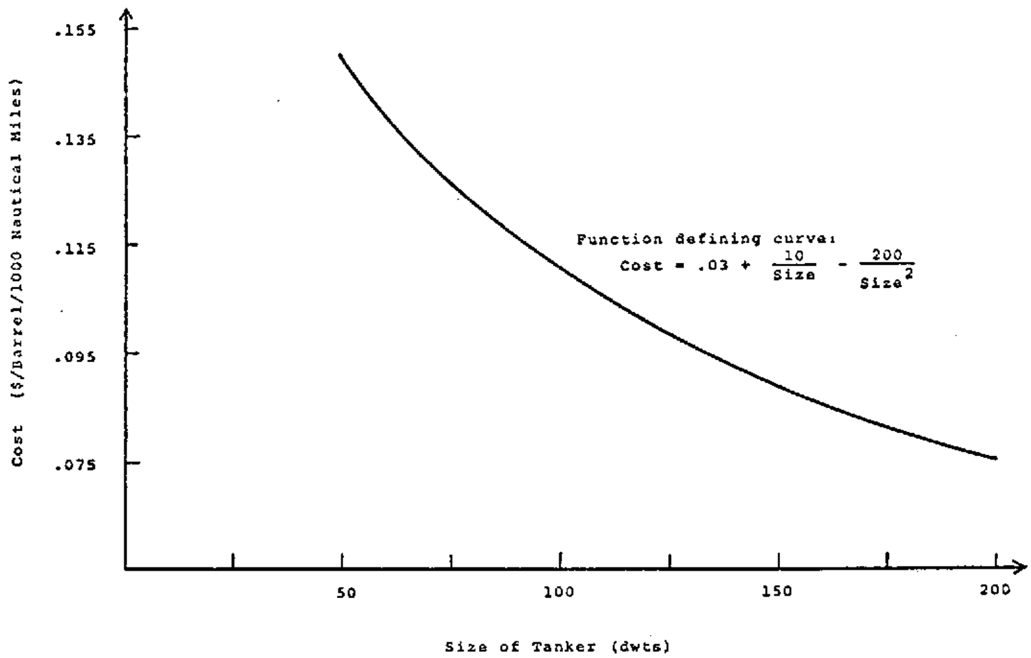


Figure 7.9 Cost of Transporting Oil on Alaskan Marine Link (1969 Dollars)

Using the cost figures in section 5.1 for the 120 K dwt tanker, the time loss of 12% (6% when using satellite information), the assumption that self insurance is equal to paid premiums, and the assumption that 30% of all damage is weather related, we get a maximum potential cost saving (δ) of

Amortization	58.0	
Other Operating Costs	33.8 x .12 =	4.06%
Insurance	9.2 x .12 x .30 =	0.33%
	100.0	4.39%

approximately 4.4% (δ = .044) at maximum

It is assumed only half of this, also, may be captured. Therefore, δ = .022 when satellite information is used.

The conservative simulation procedure of estimating the yearly benefit as [B (IV) - B (III)], as presented in the previous section, was followed. The results are presented in Table 7.33.

It was assumed that these benefits could be fully captured in SEASAT's first full operational year due to the unusual set of factors and on-going capabilities which favor this:

- all U.S. ships governed by Jones Law
- close government supervision and possible regulation
- a weather routing procedure already in operation today
- environmental concern

Table 7.33 Benefits to Alaskan Oil Marine Link ($ millions 1974)

	1987	1992	1997	1985-2000
Case Study Benefits [C(IV)-C(III)] (See Below)	9.4	3.4	1.0	66.3
C(III) - No satellite but optimal tanker utilization	421.52	246.72	160.48	
C(IV) - Use of satellite and optimal tanker utilization	412.16	243.36	159.52	

8.0 EXPLORATION AND EXPLOITATION OF OFFSHORE NATURAL RESOURCES

8.1 Civilian Applications of the Improvement in the Definition of the Geoid as Required by SEASAT Altimetry

8.1.1 Introduction and Summary

SEASAT Altimetry will have a measurement objective accuracy of ±10 cm and the data produced by the altimetry will be used to generate global sea state topography by the oceanographic community. Sea state topography results from non-gravitational phenomena which occur at sea and which cause the sea surface to be displaced from an earth's gravitational reference surface.

The topographic phenomena must be calibrated from the gravitational reference surface with an accuracy that will allow full exploitation of SEASAT's instrumentational quality if the topographic data is to yield accurate information for modeling global ocean dynamics and for developing high quality numerical weather predictions.

In particular, full exploitation of SEASAT's instrumentation quality requires that the gravitational reference surface be known to be ±10 cm, approximately, and requires that SEASAT orbital tracking be performed very accurately.

The gravitational reference surface is called the geoid. If the earth's mass distribution was uniform, then the reference surface would be an ellipsoid of revolution. Because the earth's mass distribution is non-uniform, the geoid oscillates or undulates about this ellipsoid of revolution or theoretical reference. The geoid is then defined by its positional displacement from the reference ellipsoid for all points on the earth's surface. The present geoid is defined by a 15 x 15 field or a harmonic expansion to the 15th power and an accuracy of height measurement from 3-30 meters. This resolves the gravity field spatially to about an area of 12° x 12°.

A geoid height measurement of ±1 meter would be consistent with a 1° x 1° spatial resolution and a harmonic expansion to the 180th power. A ±10 cm geoid would result in a finer spatial resolution.

As a consequence, therefore, of SEASAT's technical objectives in providing data from which sea state and weather predication can be accurately made, there is a requirement to produce a more accurate and more finely resolved geoid representation.

The geoid representation is a description of the distribution of mass anomalies in the earth's crust. These anomalies are highly significant indicators for geophysical exploration and identification of potential sources of oil, gas, and minerals in the sub-sea earth.

The basic question addressed in this case study is the ability to synthesize gravitational anomalies, i.e., to accurately locate them and estimate their magnitude, assuming a more accurate geoid is available because of SEASAT's oceanographic objectives.

Synthesis is the inverse of the problem normally investigated, namely, that of defining the geoid from gravity measurements. If synthesis appears to be possible, then a benefit from SEASAT can result if the quality of synthesis is significant to geophysical exploration for undersea resources. Improved effectiveness in gravitational anomaly location is then the source of benefit.

The answer to the basic question is to be found in the current knowledge of physics and in the techniques of mathematics. The quality of synthesis depends on the theoretical relationships between global and local gravitational phenomena. The benefit depends on understanding the influence of gravitational anomalies on geophysical exploration and the progress being made in its application, and on the application of other techniques for resource location. At this time, neither mathematical physics nor computational procedures can satisfactorily achieve the required synthesis.

8.1.2 Case Study Results

Multiple* theoretically implemented approaches to achieving synthesis relationships were explored. At this time, with only brief investigations, no technique appears to provide results with a high degree of confidence. No benefits are, therefore, possible at this time.

It does, however, seem that the problem is tractable and further research investigation will be needed to produce results in which there can be confidence. The difficulty is partially one of developing appropriate computational procedures for achieving a synthesis from observed altitude data.

The problems that are addressed in exploration geophysics appear to require an accuracy better than ±10 cm in the geoid to give gravitational anomalies which would be accurate to ±0.3 milligal. These anomalies are of interest to geophysical exploration (1 milligal is an acceleration of 10^{-3} cm sec^{-2}). Accuracy or error determination is part of the synthesis computational procedure and, at this time, appears to preclude errors less than 1 milligal.

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* These are presented in Appendix B.

8.1.3 Future Potential Cost Savings

Oil geophysicists and geologists surveyed were of the opinion that the gravity anomaly location assistance available from SEASAT would reduce the time and labor now employed for gravity surveys and could reduce the amount of seismic surveying that is necessary in oil resource exploration or prospecting.

Based on 1972 expenditures for geophysical surveys, and assuming that SEASAT's geoid application could have eliminated all of the data acquisition of rough grid seismic surveys, the following potential cost savings for 1972 were estimated.

Gravity surveys	\$ 2 million
Rough grid seismic surveys	16.5 million
	\$18.5 million

This is the magnitude of cost savings per annum that are estimated as reasonable if the the gravitational anomaly synthesis problem can be solved.

Since the case study did not result in a clear capability to effectively apply the geoid improvement to the geophysical exploration for undersea natural resources, no generalization of the case study was undertaken.

8.1.4 Other Application of the Geoid

Three main categories of practical and scientific applications of the geoid can be identified. The basis for the grouping is the data density and distribution, accuracy and precision requirements for achieving the objectives of each class.

1. Geophysical prospecting for oil, gas, and other minerals (this class is "exploration geophysics applications");

2. Definition of reference datum necessary for oceanographic interpretations and applications of satellite altimetry for improved understanding and modeling of the physical phenomena and dynamics of the oceans (this class is to be called "ocean physics applications"); and

3. Improved determination of the earth's gravity field for

   a. satellite orbit computation,

   b. missile trajectory computations and systems analysis,

   c. determination of the figure of the earth - the size and shape of the geometric figure (reference ellipsoid) that best approximates the figure of the earth - the age-old preoccupation of geodesy,

   d. geodetic datum definition, centering, and orientation required in geodetic network calculations for control point establishment, surveying mapping, which are required for economic and well-organized exploration and exploitation of continental and ocean resources and for national defense operations,

   e. definition of a unique equipotential datum for leveling operations, reductions of various geodetic and positional astronomy measurements,

   f. improvement (via the computation of gravity anomalies and/or deflections of the vertical) of error control in inertial navigation systems,

   g. rectification of continental "geoids" for correct shape, scale, orientation, and centering (these are classified as "solid earth physics applications").

Application (1) has the most stringent requirements for accuracy and density of data points per chosen unit area, while (3) has the least stringent requirements for density, but the most demand for world-wide data.

Many oceanographic measurements can benefit from knowing even a 1m geoid on a world-wide basis, but most of the oceanographic and other application areas benefit most from a 10 cm geoid. Those relating to a 10 cm geoid are below:

1. Resolution of the controversy in the difference between the mean sea level slope as determined from spirit leveling by geodesists and by steric measurements by the oceanographics, particularly along the U.S. East and West Coasts;

2. Establishment of a 10 cm absolute geoid would be an ideal reference datum for all continental leveling networks;

3. Dynamic (temporal) variation in the shape of the oceans are due to many factors including

   a. barometric pressure, heat, and salt content and their seasonal variations and the effect on the shape of the sea surface can be determined. Such variations are of the order of 10 cm to several meters,

   b. storm surges which describe the local pileup due to distant storms caused by wind and barometric pressure could cause damage and wave heights of the order of several meters when they hit coastal areas. Their prediction and direction of movement could be of importance not only for coastal areas but also for maritime ship operations,

   c. Tsunami (tidal waves) - their amplitude in the open ocean varies from perhaps a few centimeters to about one meter. These have large wavelengths of the order of several thousand km with about 1 hour period. If they are accurately detected in advance, they could prevent false alarms. If a Tsunami reaches coastal areas, it could have wave heights of several tens of meters and cause considerable flooding and damage to coastal areas,

d. sea slope due to ocean currents could cause local rise of water across the current on the order of 1 meter. This is largely due to Coriolis forces. Accurate knowledge of this will help both oceanography and geodesy.

e. ocean wavelengths of the order of 1 cm (ripples) to about 1000m for swell may be detected. Sea states of significant wave heights up to 30m will be detected,

f. tides - open ocean tide is difficult to measure at present. Of importance is the separation of ocean tides from earth tides. The combined sun and moon effect could be of the order of 78 cm. Although some of this effect may be cancelled by other factors, its knowledge and perhaps the correlation with bottom topography, thermal ocean, and air/sea interaction could lead to many scientific studies and applications.

8.2 Operation of Oil and Gas Rigs and Platforms in the North Sea Offshore Fields

8.2.1 Introduction and Summary

8.2.1.1 Introduction

Oil in the North Sea was discovered approximately four years ago. Today, there are thirteen separate oil fields and five major gas fields in the British sector; nine major oil fields and two gas fields in the Norwegian sector and several important gas fields in the Dutch sector.

Currently, about thirty mobile drilling rigs are active in the North Sea and construction of fifty more rigs is awaited. Most of these rigs are of, or will be, involved in exploration. The North Sea pool is estimated to contain twelve billion barrels of oil, or more than the reserve of the continental U.S.

British production from the North Sea is about 200 million barrels per year and is expected to grow by the end of the decade to 600 million barrels per year. Norwegian production is about 16 million barrels per year and may reach 600 million barrels per year by the early 1980's*, since Norway** intends to invest $11.5 billion in oil production during that time. The full extent of the North Sea oil field remains, as yet, to be determined. Future operations will require exploration to go further north.

All North Sea operations are conducted in an environment of high winds and substantial seas, with many storms. These storms constitute an occupational hazard which, during the winter months of 1973 alone, required insurance reimbursement of $35 million in damage. This reimbursement covered the total loss of one large rig and repairs resulting from substantial wind damage to other drilling structures.

Offshore field operations; exploration, exploitation, and production are all impeded by certain levels of severity of ocean conditions and weather. It is estimated that production is the most critical phase of the operations and is, therefore, the most susceptible to environmental conditions.

The average price of a North Sea rig is about $30 million and its daily rental is about $30 thousand. About 60% of this rental is for drilling operations, the remainder for logistical support of the rig. Operational support of a rig

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* Saturday Review - World 13 July 74
** Ogden Corporation, 1st Quarter Report

requires a variety of ancillary equipment including tugs, large supply boats, pipelaying barges, supply helicopters, and other gear needed to move and keep the rig working. The majority of equipment operations require specialized personnel and crews for operating and maintenance.

Rig operational procedures require that both crews and ancillary equipment be moved from an operating port to the operational sites, according to a prearranged contracted schedule. This is particularly true today because there is a shortage of crews and equipment, a condition that is likely to continue if world-wide growth in offshore operations can be sustained by the requisite investment capital. Therefore, if the weather and sea state conditions at the site or in transit are such, or become such, as to preclude operations, or if accidents to personnel or damage to equipment results from the weather and sea state conditions, the operations are involved in non-productive expenditures because the sea state and weather predictions are not adequate. To eliminate these, accurate reliable weather forecasts over at least a 48-hour forecasting interval would be sufficient. Thus, the maximum cost saving from SEASAT to the North Sea oil production operations is that represented by non-productive operational expenditures due to inadequate weather and ocean condition prediction.

Offshore oil production is an involved procedure with many operations. Current methods for offshore petroleum production locate a fixed platform in areas which have significant production potential, as determined by test drilling with equipment designed for this task. After proving a field, the production platform is erected and production drilling begins. Up to 15 wells can be drilled from the same production platform. Pipelines are laid from neighboring platforms to shore or to an offshore storage tank. Erection of the necessary structures and pipelines is extremely sensitive to environmental factors, while the drilling and extraction is relatively insensitive to weather and sea conditions. The installation of the drilling platform and pipeline facilities are accomplished in the following steps, some of which take place concurrently -

1. Mobilization of the production drilling platform and support equipment.
2. Movement of equipment and platform to the drilling location.
3. Installation of the platform.
4. Drilling of the production wells.
5. Mobilization of the pipelaying barge(s) and supply vessels.
6. Movement to the work site.
7. Installation of the connections (pipe riser or vertical pipe section).
8. Laying of the pipe (occasionally done from both ends).
9. Burying the pipe on the sea floor.
10. Retrieval of the production drilling rig.
11. Movement of the reusable equipment to the next job.

All of the equipment movement and installation operations are sensitive to weather and sea conditions. The speed of barge towing to the site depends on wave height; installation of a platform or the pipe connections requires several days of calm weather. The rate at which pipe is laid is dependent on wave height and must be stopped when waves exceed certain heights. While the pipelaying barge can hold the pipe sting in some conditions until the severe weather subsides, repeated flexing in the same parts of the pipe may cause it to buckle. For this reason, the barge must continue to lay pipe, but at a greatly reduced rate while keeping the pipe under a tension which is approximately 85% of the breaking tension. If a severe storm is forecast, barge personnel must cap the pipe and place it on the bottom while maintaining tension. The structure which supports the pipe to keep the bending radius large, which is called the stinger, must also be lowered or stored on the barge. Lowering the pipe without damage can take as long as 12 hours before the barge can start for shelter, at rates under 10 knots. When the storm subsides, the equipment must be towed back and the line retrieved. Re-establishing the laying operation usually takes at least one 12-hour shift after the return trip.

Pipelaying barges frequently are multipurpose units, doubling as derrick barges used in the installation of platforms. The increasing demand for all offshore equipment and for equipment which is less weather-sensitive has impelled development of pipelaying ships and semi-submersibles. A new design pipe barge is expected to be able to hold in 20-foot waves and a new "ship" being designed for that purpose is expected to hold in 45-foot waves. Table 8.1 includes data on maximum capabilities for pipelaying vehicles and other equipment designs. If the new designs prove to be acceptable, much of the current dependence of pipelaying on calm weather can be reduced, however, efficiency is still expected to be a function of weather.

Table 8.1 Work Capabilities at Maximum Wave Heights of "Typical" Offshore Equipment

Type	Wave Height*	Source
Old Pipelaying Barge	6-8 ft - Holds at 8 ft	OTC Paper No. 1359 April 1971
New Design Supply Boat	10 ft - Transfers supplies	Offshore, March 1973, p 62
New Design Pipelaying	20 ft - Holds	Gas and Oil Journal, September 3, 1973, p 48
New Design Pipelaying Ship	≤45 ft - Holds	Ocean Industry, February 1974, p 31
Semi-Submersable Drilling Platform	35 ft - Marginal Drilling	Ocean Industry, May 1973, p 51
Fixed Platform	>55 ft - Marginal Drilling	Several

*The wave heights indicate upper limits for effective operation. At greater heights, operations must cease.

8.2.2 Case Study Results

The case study, assuming an operational SEASAT, developed oil production cost saving estimates. The development was based on non-productive operational incidents that resulted from inclement weather, as recorded on an actual daily operating project log.

The results obtained relate to a three platform oil production operation with thirty-eight miles of pipe to be layed. The operating incidents produced by storms are identified as

- accident avoidance
- avoidance of pipelaying barge costs
- avoidance of derrick barge costs

Cost savings were determined from daily operating costs for labor and equipment based on the number of incident days recorded in the project log. It is assumed that accurate and reliable weather and ocean condition prediction would have eliminated from the scheduling the conditions that produced the losses. The determination of these cost savings resulted from the following procedure.

The daily progress reports of the project log (see Appendix A) were examined to categorize the day's activity as working, pipelaying and amount laid holding due to weather, towing, etc. Some error in assignment is attributable to the briefness of the daily reports. When the reports were ambiguous as to the amount or quality of work, the day was classified as a working day. When the daily report indicated more than half the day was spent "standing by", this was classified as holding, usually due to weather. Delays due to equipment failure were usually classified as a working day. There is a correlation, not perfect, between the 6 a.m. sea state report and the amount of pipe laid; breakdown of equipment prevents a clear demonstration of the correlation with the currently available data. Supply problems caused by rough seas were explicitly mentioned only once in the daily progress reports. The project supervisor stated that this occurred several times.

The time considered was from July 4 (the start of offshore operations in a non-specified year prior to 1971 operations) to April 21 of the following year, when no more reports were available as the work was almost complete and the supervisor was transferred. The period covers 290 calendar days during which the pipelaying barge and its ancillary dredging barges were committed to the job. During this time there were two periods totaling 26 days during which two derrick barges and ancillary equipment, similar in size and charge rates to the pipelaying barge were in use for the highly weather sensitive job of lifting the main deck of the production platform onto the platform legs. After the deck was placed, these barges remained at the platforms as work barges, a much less environment sensitive function. For the computation of benefits due to improved weahter and ocean condition knowledge, the two derrick barges are considered only during the 26 days they were committed to the placement of the three platform decks. The pipe barge was committed to the job for 272 days including days spent in laying the smaller and shorter branch lines to the two platforms and as a work barge for making connections, testing, etc. Details of the above work were not reported in a manner suitable for detailed analysis. Hence, 272 pipelaying barge days and 52 (2 x 26) derrick barge days are counted as 324 equipment days.

By examining the tabulated comparison of the progress reports (Appendix A) with the weather reports, it is estimated that there were 97 equipment days for which some savings in charges would have accrued to the operation if a reliable 48^{+} hour forecast had been available.

The savings claimed are based on current practice in charging for equipment and labor in separate rates. There is a working rate (full rate) and a weather rate (reduced rate) which covers the equipment rental and a minimal crew. The full working rate is charged when the barge is standing-by for the weather to improve. If some of the personnel can be sent back to port, their costs are not charged. When the barge is towed to port, only the weather rate is charged while in port. When making a fixed-price bid, as is done in calmer waters such as the Gulf of Mexico, the contractor loads the bid to cover weather and other risks. Hence, even in calmer waters, oil companies frequently self-insure the weather risk and contract on a day rate basis.

The current rental rate for barges, ancillary equipment, and crews for this type of equipment in the North Sea is approximately $100,000 per day, of which approximately 25% to 30%, or $25,000, is due to reducible labor charges. When equipment is committed to a contract, the equipment charge is not reduced when not working; hence, any savings would come from reduction in labor charges. These estimates are "typical" costs as given by Brown & Root, Inc. A typical charge for the pipelaying barge with crew but without the ancillary equipment and crews is $50-$55,000 per day.

Of the 97 equipment days for which a savings might have been possible, given a reliable 48^{+} hour weather forecast, 11 were due to weather related accidents to the stinger or pipe support pontoon when the weather worsened so quickly that the pipe could not be released and the stinger retrieved satisfactorily. During the period of repair, some personnel such as divers and supply vessel crews can be sent home while others such as welders and crane operators are usually needed for the repair work. As no estimate of this division is available, the assumption was made that 50% of the labor charges would be saved when the barge is in for repairs.

It is noted that the accidents occurred early in the project and may reflect "learning" as well as being weather related.

Since the time of this project, the practice of having two stingers available for each job has developed. This will greatly reduce the downtime due to stinger repair, but not for the pipe if it buckles when lowered. These new stingers have also grown in size and costs have increased from approximately $100K to $1M. In making estimates for the 1980 period, one must also consider the greater severity of the weather in the northern North Sea over that in the southern sector. Because of these offsetting factors, the ratio allowance for accident reduction is not given any special treatment for improvements in technology or work methods.

Of the 272 working days for the pipelaying barge, 64 days were found for which there would have been a labor charge savings based on a reliable 48^+ hour forecast. Typically, these were periods spent holding over several days waiting for weather to improve. When the weather forecast did not improve, the barge was towed toward port. Frequently during the tow, the weather would appear to be getting better so the barge was towed toward the work site only to have the weather deteriorate again. The holding and towing time was counted as days for which a savings could have been made; the time spend in port was not counted. Short holds for two or three days also were not counted as potential opportunities for savings.

During the 26 days that the two derrick barges were committed to the task of lifting the main production platform deck onto the legs, 11 days were spent holding or towing due to weather conditions. As an indication of the water calmness necessary to install the platform deck, 6 of the 11 days spent waiting were also days during which pipe was being laid. Because much of the other effort in installing the platform legs and finishing of the platform work is not severely weather sensitive, and halts only during the worst weather, this other work was not considered in the analysis.

Given the above estimates of operating days that could have been saved based on a 48^+ hour forecast, it is also possible that total project time would have reduced. Thus, additional benefit would accrue based on capital productivity. The computation of such benefit, however, is not straightforward. It requires site/project specific schedule integration knowledge. In this analysis, only the former categories of benefits - avoidable downtime - are counted; thus yielding somewhat conservative estimates.

The computation of the cost savings and ratios to be applied to any generalization of North Sea operations proceeded as follows:

The working day rate is $100,000 in 1974 dollars, of which $75,000 is equipment rental and fixed, and $25,000 is labor charges which may result in a savings if the personnel are not held at the job.

Accident days saved with a reliable forecast are estimated to be 11 of 272 days with a 50% savings estimated on labor rates and 100% savings on equipment rental. The savings for this specific project would have been 11 x $87,500 = $962,000 and the estimated ratio of accident days to be saved is 11/272 = 0.04 = 4%.

Pipelaying barge days saved with a reliable (48^+ hour) forecast are measured as 64 of 272 with a 100% savings on reducible labor charges. The savings for this job would have been 64 x $25,000 = $1,600,000. The ratio of pipe barge weather rate savings is estimated at 64/272 = 0.235 = 23.5%. Derrick barge days saved with a reliable forecast are measured as 22 of 52 based on the use of two barges on 26 days for placing three platform decks. As only the labor charges while holding are saved, the savings are estimated as 22 x $25,000 = $550,000. The ratio of derrick barge days saved during this specific task are estimated as 22/52 = .423 = 42.3%. The total estimated cost savings possible for the tasks examined are approximately $3.1 million. This cost saving resides in the oil production operation and essentially reduces the cost of producing oil in the North Sea operations, by whatever fraction of the maximum cost savings is captured by the operation. These cost savings are summarized in Table 8.2.

Table 8.2 Summary of Case Study Cost Savings

Maximum Operational Cost Savings Per Annum from Non Productive Operating Costs	$3,112,000 (1974 $)		
Number of Production Platforms	3		
Miles of Pipeline Layed	38		
Number of Operating Calendar Days Per Annum	272		
Working Day Operating Costs Labor $25,000 per diem Equipment $75,000 per diem	$ 100,000		
Weather Day Operating Costs (Equipment plus Minimum Crews)	$ 75,000		
Operation Incident	**Accident**	**Pipe Laying Barge**	**Derrick Barge**
Incident Occurrence No. Operating Days	11	64	22
Daily Cost ($)	87,500	25,000	25,000
Incident Cost Savings per annum ($)	962,000	1,600,000	550,000

Assumption: i) SEASAT operational capability available (1985)
ii) Operating incident data prior to 1971

8.2.3 Case Study Generalization

8.2.3.1 Introduction

This generalization can be developed in two steps. The first step concentrates on the continuity of North Sea oil production in which the weather impact is approximately constant. The second step expands the generalization to the growth in offshore oil production world-wide, in which the weather impact is expected to be widely variable.

To effectively generalize from the case study, the world-wide projection of offshore oil production must be made and the planning horizon for each location must be related to the estimated oil reserve at each location. The impact of the weather on oil production at each location must also be determined relative to the case study weather implied by the daily operating project log obtained in the North Sea case study (Section 8.2.2).

The case study treats only three production rigs and 38 miles of pipeline. Each site production cost saving, because of improved forecasting depends on the quantity of equipment and labor involved. For these reasons, the case study generalization requires a factor of multiplication to define the equipment/labor relative relationship for each offshore production site. This can be estimated through the relative oil production at each site.

In 1973, some 486 rigs and platforms operating offshore drilled a total of 1600 wells, and in 1972 offshore production was 3.3 billion barrels of oil, or about 18% of the world's output.

A recent U.N. study* estimated about 115 billion barrels of offshore oil, world-wide, proved and recoverable, or about 18% of the 640 billion barrels of oil estimated to exist in total beneath the seas and the land. Estimates by geologists predict offshore's oil contribution to eventually be up to 50% of this total.

With deep ocean water oil included, L. G. Weeks, a geological consultant,** has estimated an eventual total of offshore oil of 2,272 billion barrels, including gas. (Gas is converted assuming 6,000 cubic feet of gas is equivalent to one barrel of oil.)

Exploration is underway in about 100 different countries with a water boundary. Production exists in about 40 of these.

The extent of offshore production is evidently dependent on the growth in demand for oil, which is dependent on the world-wide efforts to determine and utilize other forms of energy and on pollution control requirements. The supply of oil and the extent of exploration into the offshore hazardous ocean regions will also be dependent on the availability of investment capital for all phases of the oil industry's growth.

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* Economic Significance in Terms of Mineral Seabed Resources of the Various Limits Proposed for National Jurisdictions. Prepared for the Secretariat, U.N. Secretary-General, June 4, 1973.

** Geological and Technical Aspects Specific for the Exploration for Oil and Gas on the Continental Shelves. World Petroleum Congress Moscow 1971.

8.2.3.2 Generalization Modeling

8.2.3.2.1 Introduction

The data available relating the weather influence to operational cost savings potential is based on environmental observables in the southern region of the North Sea. If the total offshore oil production distribution throughout the world's seas could be completely modeled, it is presumed that the fraction of sea based sites that would be radically influenced in their operations by 48^+ hour sea state and weather prediction would be small.

In defining viable benefits, it is reasonable to seek reliable, conservative values. It is, therefore, the intention in this generalization to concentrate on reasonable estimates for the North Sea cost savings and to attempt to expand to world-wide production by simpler estimating.

Cost savings derived from the North Sea require a weather and ocean condition prediction interval of at least 48 hours. Hence, full benefits cannot be developed until the operational SEASAT is available, which is not before 1985. The interim SEASAT-A (and SEASAT-B) could make some contribution to the North Sea benefits but this would require the North Sea region to be sampled and the implementation of an operational demonstration to produce the required 48^+ hour weather and ocean condition forecasts for this region. In the absence of a commitment to perform an operational demonstration of this sort, the benefits will be treated conservatively and will be considered not to accrue until the implementation of an operational SEASAT.

8.2.3.2.2 Modeling and Cost Savings in the North Sea

When an operational SEASAT is available, oil exploration will have moved further northward in the North Sea into regions in which the weather and ocean conditions are more violent than the region from which the operating log of the case study was obtained. Thus, the case study weather influence would be conservative for this generalization. By 1980-1985, oil production will have increased in the North Sea and production displacement will require longer and possibly larger pipelines than in the case study result.

North Sea oil production is predicted to triple by the 1980's (OECD oil p.250) to about 600 million barrels per year or about 1.6 million barrels per day. Battelle, in developing their case study, assumed that North Sea production in the 1980's would be performed by 7 production platforms. The American Petroleum Institute estimates that a production rig can produce between 20,000 and 100,000 barrels per day. As a minimum, therefore, the API data would require 16 production platforms in the North Sea in the 1980's.

To support the production platforms pipe is required to be layed. To handle multiple inputs and the greater distances expected in 1980, the pipe is assumed to be 60 inches in diameter. For fewer platforms, the pipe length required is assumed to be 250 miles; for 16 production platforms, the pipe length would be proportionally longer.

Thus, the basic model of the North Sea oil production in the 1980's, when SEASAT becomes operational, is that of seven rigs and 250 miles of pipeline.

Extrapolating from the case study results, i.e., from a model of three rigs and 38 miles of pipeline, the annual operating cost savings are tabulated as follows using saving ratios derived in the case study.

North Sea 1979-1985 Oil Production Cost Savings

A. Accident Avoidance

Projected Weather Related Accident Avoidance Ratio	4%
Number of Pipelaying Barges (50 miles of pipe each)	5
Length of Work	365 days
Daily Savings of Avoided Accidents (100% equipment costs	$75,000
+ 50% labor costs)	+$12,500
	$87,500
Potential Savings = .04 x 5 x 365 x $87,500 =	$6,387,000

B. Pipelaying Labor Charge Savings

Projected Weather Downtime Labor Charge Savings Ratio	23.5%
Number of Pipelaying Barges	5
Length of Work	365 days
Daily Savings on Labor Charges	$25,000
Potential Savings = .235 x 5 x 365 x $25,000 =	$10,720,000

C. Derrick Barge Labor Charge Savings

Projected Weather Downtime Labor Charge Savings Ratio	42.3%
Number of Barges Required per Platform Erection	2
Number of Platforms Constructed in Year	7
Number of Days Committed to Task	10
Daily Savings on Labor Charges	$25,000
Potential Savings = .423 x 2 x 7 x 10 x $25,000 =	$1,480,000

Total Potential Savings = A + B + C = $18,600,000 (1974$)

An alternative model would be 16 rigs with 571 miles of pipe to be layed. This would produce a cost saving that is measured by a factor 2.5 approximately to $46.5 million (1974$).

Extrapolation from the case study, which treats oil production in the southern North Sea, was developed as follows.

Exploration work is moving to the northern North Sea and to the west of Britain where the weather is more severe. The contractors are also investing in equipment of higher capabilities and much higher cost. The water depths for both exploration and exploitation are increasing, as is the distance from shore. One of the major effects these factors will have on potential benefits is that the equipment will have to hold at station for all but the longest storms because towing to shelter at less than 10 knots would take more than a day each way. If wage savings are to occur, the work crew would have to be flown back or transported to shore by high-speed boat as is current practice. A minimum barge crew would then remain on station and be charged to the contracting company.

In the case study, cost savings ratios were estimated against different operational costs as follows:

Accident Avoidance	0.04
Pipelaying Barge	0.235
Derrick Barge	0.423

Evaluation of these factors to determine any adjustments to the calculated ratios for savings based on reliable 48^+ hour forecasts in 1985, has led to the conslusion that they should not be changed. The chief factor considered is the conservative projection of activity. If improvements in technology reduce operational weather sensitivity, these improvements will be implemented only if test drilling indicates sufficient oil deposits to justify the investment, which implies increased activity. Improvements to overcome some of the current limitations due to weather will require large additional investments and still not eliminate weather dependence. Thus, the improvement ratios are used without trend adjustments to compute the expected savings in 1985. North Sea activity as a function of time is illustrated in Table 8.3.

Based on the projections of Table 8.3, seven production platforms and 250 miles of pipeline will be layed using 10 lay barges in 1985. The number of lay barges appears to be high in relation to the length of pipelines; hence, it

Table 8.3 Estimated North Sea Offshore Oil Activity as a Function of Time

Facility	'74/'75	'76/77	'78/'79	Total Installed (where applicable)
Production Platforms	13	14	14	50
Submarine Pipelines	400	400	500	1,400 miles
Storage Spars	1	2	2	4
SPBMs	3	4	5	12
Semi-Submersibles	38	42	50	-
Drillships	2	3	4	-
Supply Vessels	70	120	180	-
Lay Barges	4	7	10	-
Rig/Platform Tenders	40	65	90	-
Diving Systems	40	70	90	-
Subsurface Craft	2	4	6	-
Repair Ships	2	5	8	-

"Estimated Equipment Requirements for North Sea Oil & Gas Recovery", J.W.Rasmussen, Ocean Industry, February 1974, p.27.(6)

is assumed that the lay barges also are used as derrick barges. Five pipelaying barges are assumed to lay 50 miles per year (versus 38 miles in 272 days in the case study), while the other five barges are available for other work such as the erection of the seven platforms. The five barges work a full year of 365 days at a rate of $75,000 (1974 dollars) per day for equipment and $25,000 for labor charges. Labor charges are eliminated whenever the crew is released due to forecasted inclement weather predicted via SEASAT data. Through reliable weather forecasts, the pipelaying barges avoid accident downtime of 4% saving $6,387,000 (.04 x 5 barges x 365 days x $87,500). Also, labor charges during 23.5% of the days when he weather is predicted to be too rough to work effectively would be avoided resulting in a savings of $10,720,000 (.235 x 5 barges x 365 days x $25,000).

The derrick barges are used to emplace seven production platforms, two being committed for an average of 10 days each per platform for this weather sensitive task. Through the use of a reliable forecast, labor savings of $25,000 per day for 42.3% of the days are projected, thus saving $1,480,000 (2 barges x 10 days x 7 platforms x .423 x $25,000).

Thus, based on a conservative estimate of seven production platforms and 250 miles of pipeline construction in the North Sea during 1973, an estimated $18.5 million per year can be saved on the basis of labor charges avoided by releasing the work crews if reliable weather and ocean conditions forecasts are available through SEASAT. As there is currently a projected shortage of skilled personnel for work in the offshore area (especially welders), these personnel are expected to be available for onshore prefabrication during all but the shortest weather delays, and wage rates would be adjusted upward to cover the furlough time.

This derived cost savings of \$18.5 million evolving from seven production platforms appears to be too small based on current data describing the production capacity of a platform.

The North Sea 1985 production which is estimated to be 600 million barrels annually would require each platform to produce approximately 250,000 barrels per day. The current API maximum daily production per platform is 100,000 barrels per day, and ranges with current technology from 20,000 to 100,000 barrels per day.

Unless, therefore, production technology changes radically by 1985, a conservative upper bound to the North Sea saving will be \$(18.6 x 2.5) million per annum or \$46.5 million per annum. At this time, this particular magnitude of saving is thought to be more representative than \$18.5 million per annum, and it will be used in the future generalization.

As this cost saving computation relates to the North Sea, one of the roughest sea areas, caution must be used in extending it to other areas.

8.2.3.2.3 Modeling and Cost Savings in the Rest of the World

8.2.3.2.3.1 Introduction

In this generalization, the world offshore oil production will be projected up to the year 2000 in a conservative manner. From this projected production, the number of production platforms will be estimated using a range of 20,000 barrels per day to 100,000 barrels per day as the production potential per production rig. The geographical distribution of world-wide production based on the latest available data, 1973, will then be estimated. The geographic data will then be used to estimate the influence of weather in each production region, relative to that in the North Sea.

The weather relativity level selected is that where winds exceed Beaufort 7 on the Beaufort Scale. Such winds make small ship operation hazardous and it is assumed that this relativity is valid, in general, for offshore oil production.

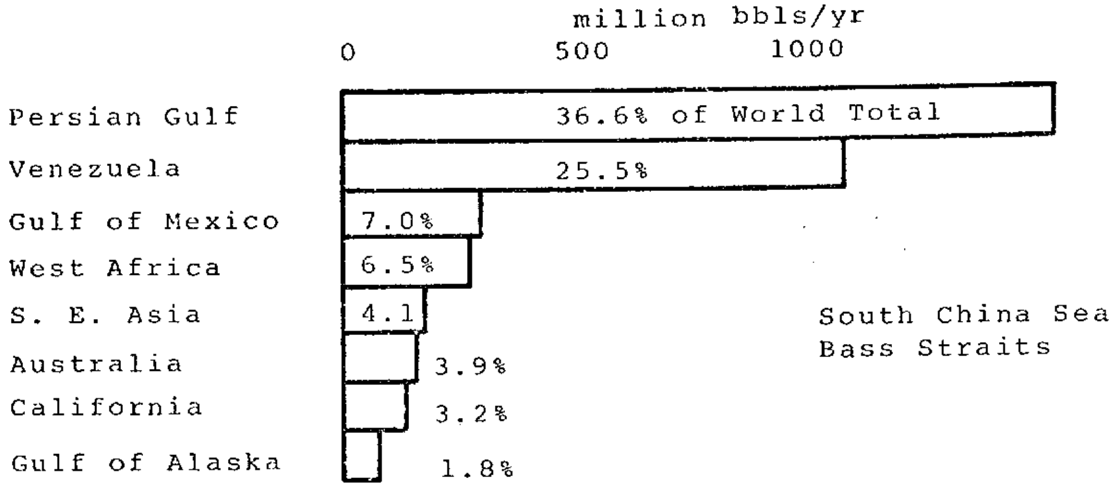
The amount of pipelaying in each production operation in each geographic region is assumed to be 250 miles, as in the North Sea generalization. It is not possible to be more precise about the quantity of pipe required, but the figure of 250 miles is estimated to be reasonable. In the Gulf of Mexico, for example, the amount of oil production pipe varies from 0 miles to about 175 miles today as a function of producing platform location. However, since this projection extends to the year 2000, it is expected that the pipe requirements will generally tend to grow in length.

Thus, the basic objective in this generalization is to develop a simple ratio for multiplication of the generalized North Sea cost savings: which will be representative of the influence of SEASAT derived data on the world offshore oil production, in general.

8.2.3.2.3.2 World-Wide Offshore Oil Production Generalization

Figure 8.1 illustrates the major geographical areas of offshore oil production in the world. These major geographic regions account for 88.6% of the world offshore oil production in 1973, some 3.3 billion barrels per annum. The remaining 11.4% cannot be easily accounted for geographically, although production is or has occurred in the Adriatic Sea, Indonesia and Malaysia, and evidently the North Sea.

Regions of current exploration or interest such as the Canadian East Coast, the Canadian Arctic, and offshore East Coast United States may become major producers in the future and could modify this analysis. A tentative estimate of such production shifts will be made subsequently.



TOTAL: 88.6% of World Total Offshore Production

Reference: Oil and Gas Journal, May 6, 1974, p. 196ff

Figure 8.1 1973 Distribution of Offshore Oil Production, by major offshore producing areas

It will be assumed that this geographic distribution will be representative of oil production offshore until the year 2000. Implicitly, this assumes that oil reserves are adequate to the task of growth in oil production, although this has not been determined.

Figure 8.2 assigns to each geographic region of Figure 8.1 and the North Sea the frequency in percent of the time per annum with which winds exceed or equal Beaufort 7. Each production region is then assigned a relative ratio with respect to the North Sea which is representative of the relative weather influence in each geographic region of production.

World Offshore Production Percentage	Major Offshore Producing Area	Beaufort Frequency (%) 1) 2)	Beaufort Frequency/ Frequency for North Sea	Weighted Relative Frequency %
2.5	North Sea	10	1.0	2.5
7	Gulf of Mexico	2	.2	1.4
25.5	Venezuela	0.5	.05	1.275
3.9	Bass Straits	14	1.4	5.46
4.1	South China Seas	0.3	.03	0.123
1.8	Gulf of Alaska	9	.9	1.62
36.6	Persian Gulf	0	0	0
6.5	West Africa	1	.10	.65
3.2	California	0.5	.05	.16

World Multiplying Factor Relative to the North Sea $= \frac{10.688}{2.5} \cong 4$

Reference: 1) U. S. Navy Marine Climatic Atlas of the World
Navair 50-1C-54 1 March 1969

2) U.S. Department of Agriculture, Weather Bureau
Atlas of Climatic Charts of the Oceans, 1938

Figure 8.2 Annual Mean Frequency of Winds ≥ Beaufort 7 and World Production Multiplier

Each regional weather factor is then weighted by the regional contribution to world-wide production of offshore oil.

If P_R and P_{NS} is the production in the region and in the North Sea, respectively, and W_R and W_{NS} are the weather factors in the region and the North Sea, respectively, then if B_{NS} is the North Sea benefit, the world benefit B_W is given by

$$B_W = \frac{B_{NS}}{P_{NS}} \sum P_R \frac{W_R}{W_{NS}}$$

$$= \frac{10.7}{2.5} B_{NS}$$

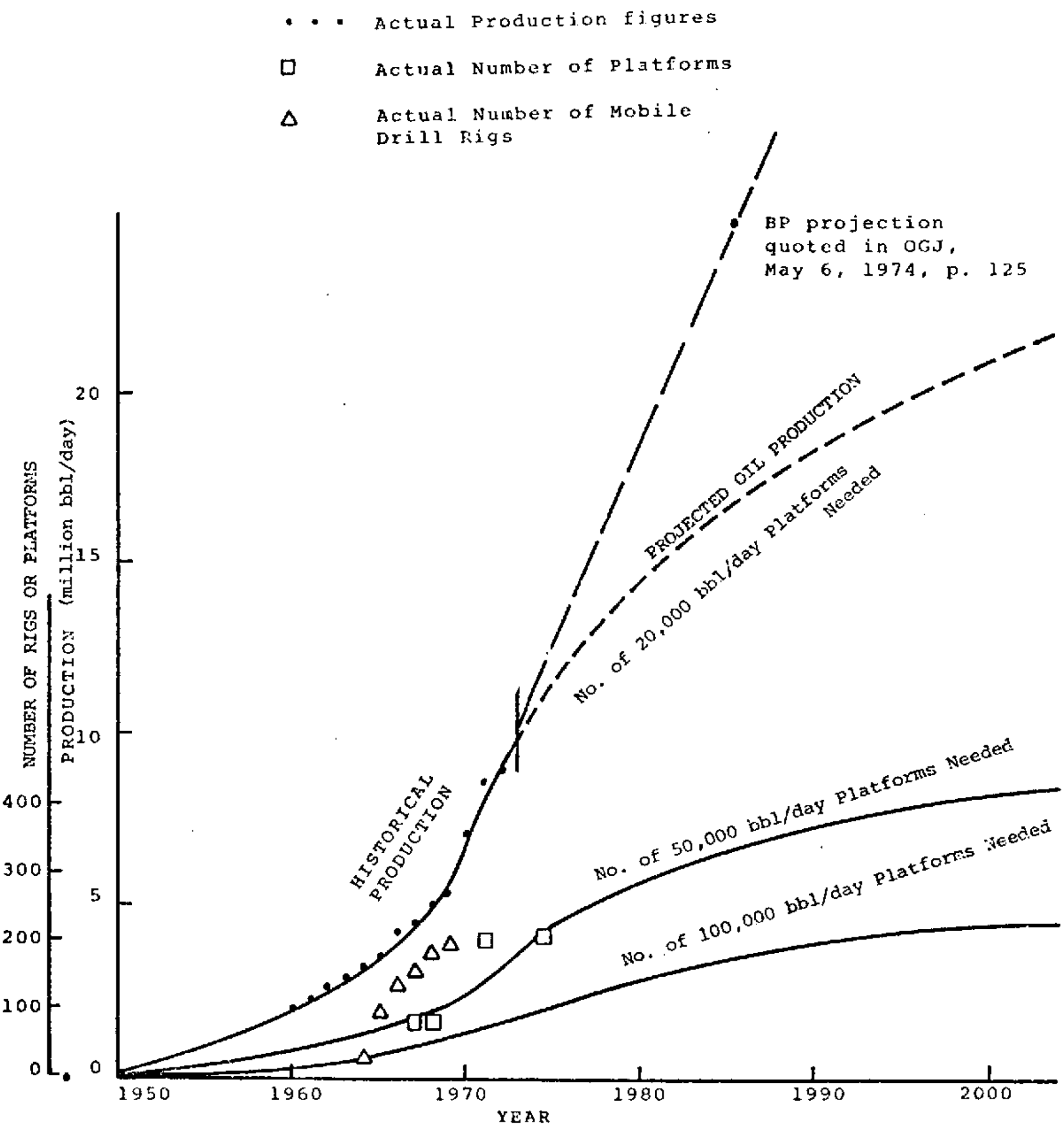
or $$B_W = 4 B_{NS}$$

The value of B_{NS} derived in the case study is $18.6 million. This value requires a production output per production platform of about 250,000 barrels per day. A more reasonable platform production would be 100,000 barrels per day which would increase the benefit to $46.5 million.

Hence, the offshore oil world would benefit from SEASAT lies between $74.4 million and $186.0 million (1974$).

Figure 8.3 is a conservative projection of the offshore oil production in the world as a function of time. In 1974, each production platform is estimated to have produced an average of 50,000 barrels of oil per day. According to the American Petroleum Institute, a platform can produce between 20,000 and 100,000 barrels of oil per day.

In 2000, the estimated oil production is 1.3 times the 1985 production.



Reference: Oil and Gas Journal Annual Offshore Reports 1964 - 1974

Figure 8.3 World Offshore Oil Production

As an estimate for each year between 1985 and 2000, the expected cost saving, C_E, for the rest of the world's off-shore oil production could be set at

$$C_E = 1.15 \times (\text{Cost Saving in 1985})$$

and this could range from $85.6 million (1974$) per annum to $214 million (1974$).

8.2.3.3 Possible Global Benefits Due to Shifts in Geographic Production

The current analysis has assumed that the 1974 geographical distribution and output will remain in force, essentially until the year 2000. This assumption is a conservative one in terms of the possible SEASAT benefit, because of the influence of the weather factor.

It could be argued, in particular with respect to U.S. oil objectives of self sufficiency, that exploration and production will be accelerated in regions such as the Gulf of Alaska, the East Coast of the U.S., and the Canadian Arctic. These developments would require considerable capital investment and would most likely result in expensive oil.

To illustrate the influence of such an oil production policy, the following simple analysis is developed.

Referring to Figure 8.2, if the oil production of the Persian Gulf, currently 36.6% of the world total, is replaced by oil production from a region more favorable to the U.S., but one where the Beaufort weather factor is close to unity as in the North Sea, then the world benefit multiplier would go from approximately 4 to

$$\frac{10.688 + 36.6}{2.5} = \frac{47.7}{2.5} = 19$$

If such a transition is assumed to occur uniformly from 1974 to 2000, then the incremental benefit per annum would be 0.55

approximately. By 1985, the SEASAT benefit would be approximately increased to a factor of 10, to give an average benefit multiplier to the year 2000 of 14.5, giving an increase over the current estimates by a factor of 3.8. Thus, the estimated benefits would range from $325 million to $813 million (1974$), if such an oil production policy was adopted.

8.2.3.4 Offshore Oil Production Generalization Results

The cost savings to the North Sea offshore oil production operation in 1985 is estimated to be $18.6 million (1974$). On the basis of the production platform population required to produce the 1985 North Sea estimated production, it could realistically be $46.5 million (1974$). It is estimated that this is an annual cost savings durable until the year 2000.

The cost savings to the offshore oil production of the rest of the world in 1985 is estimated to be between $85.6 million (1974$) and $214 million (1974$). This is expected to be an annual cost saving also durable until at least the year 2000.

The derived cost savings, reside in the oil production operations and, if captured, they have the potential to reduce the cost of production of offshore oil. In general, it is difficult to categorize these cost savings as maxima; they are reasonable cost savings estimates. The time durability of the cost savings estimates is based on the general operating fact that, over the years, production costs rise and it becomes cost effective to continue oil exploration and develop additional reserves. Thus, this annual saving can be expected to continue until oil is no longer produced in the offshore regions. How long this production period will be depends on the time that profitable extraction of oil from the regions will continue, a factor dependent on the generation of oil reserves in each geographic region.

The cost saving in the North Sea is neither a captured benefit nor is it a social benefit to the U.S. A social benefit to the U.S. can only be developed through price of the North Sea oil. Insofar as the North Sea production will satisfy the needs of the nation's exploiting the oil and reduce their requirement for Mid-East oil, Mid-East oil will be in less demand. Insofar as the U.S. is dependent on Mid-East oil, this lessened demand <u>can</u> reduce the price to the U.S. consumer of products derived from Mid-East oil. That it <u>can</u> does not say that it <u>will</u> because of the many intermediate steps involved in the oil distribution.

The annual cost savings, instead of being accumulated, can be employed each year to offset the production cost of oil. If the North Sea production is considered to be that of the United Kingdom, then the reserves already existing are believed to be adequate to yield a production of 75 million tons of oil per annum during the 1980's. Since the oil specific gravity is not known, an average factor of 7.3 will be used for the conversion of barrels. Hence, the annual North Sea production is 548 million barrels of oil per annum or, assuming 274 production days per annum, 2 million barrels of oil per day.

The production cost of offshore oil depends on the depth of water and the size of the field.

Assuming that this production would involve costs similar to a 0.3 million barrels of oil per day field in 165 feet of water, the production cost would be 15-21* cents a

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* Ogden Corporation First Quarter Report, 1974.

barrel. The annual production cost is then between $82 million and $115 million. If the production cost saving from weather prediction is approximately $19 million, the weather prediction can save from 17% to 27% of the production cost of this oil each year.

8.2.4 Drilling Rig and Platform Design

8.2.4.1 Introduction

Offshore structures located and operating in a sea environment are subjected to the stresses and strains that result from this environment's non-gravitational displacements and motions.

To function effectively in its operating environment, a structure must be designed to withstand the stresses and strains that the environment will create during the life of the structure.

Insofar that SEASAT derived data will better define the time statistics of variation of the characteristics of the environment that contribute to structural stress and strain, SEASAT will offer an opportunity to more precisely design the structures. Whether or not this opportunity can be taken advantage of depends on the current state of relationship and understanding between sea forces (static and dynamic) and the properties of materials suitable for sea structures. To the extent that knowledge is imprecise, the structural design compromise must embody safety factors. The safety factors selected must relate both to imprecision of knowledge in the properties of the materials used and the structures' environment, and introduce additional structural design and fabrication costs.

It is, therefore, possible that SEASAT derived data will help to clarify the structures operating environment and to provide cost savings both through design and fabrication, as well as through the improved utilization of the structures.

The overall result of a successful application and integration of SEASAT derived information with structural materials knowledge and refined structural design may reduce the risk of damage or loss of the structure in its operating environment. As a range of alternatives, this may be accomplished without reducing the acquisition cost, or it may not change the risk but only the acquisition cost. Whatever alternative actually results, it will be difficult to precisely relate the alternative to SEASAT's contribution.

As rigs and platforms become more common, and as offshore oil production becomes more significant, and exploration extends to deeper water, it will be a natural consequence to seek efficiency in the design of the required sea structures without SEASAT's contributing information. SEASAT's information may then just speed up this design efficiency achievement by some amount.

8.2.4.2 Rig and Platform Loss and Damage Risks

SEASAT's contribution to improvement in design through reducing uncertainties in wave height, wave group velocity, and wind speeds, will, it is assumed, reduce the risk of loss or damage to rigs and platforms in use in offshore operations throughout the world.

Figure 8.4, which is based on Shell Oil's insurance claims during the period 1955-1971, attempts to define the risk of loss or damage to offshore oil structures in different depths of water. The information is specific to Shell's

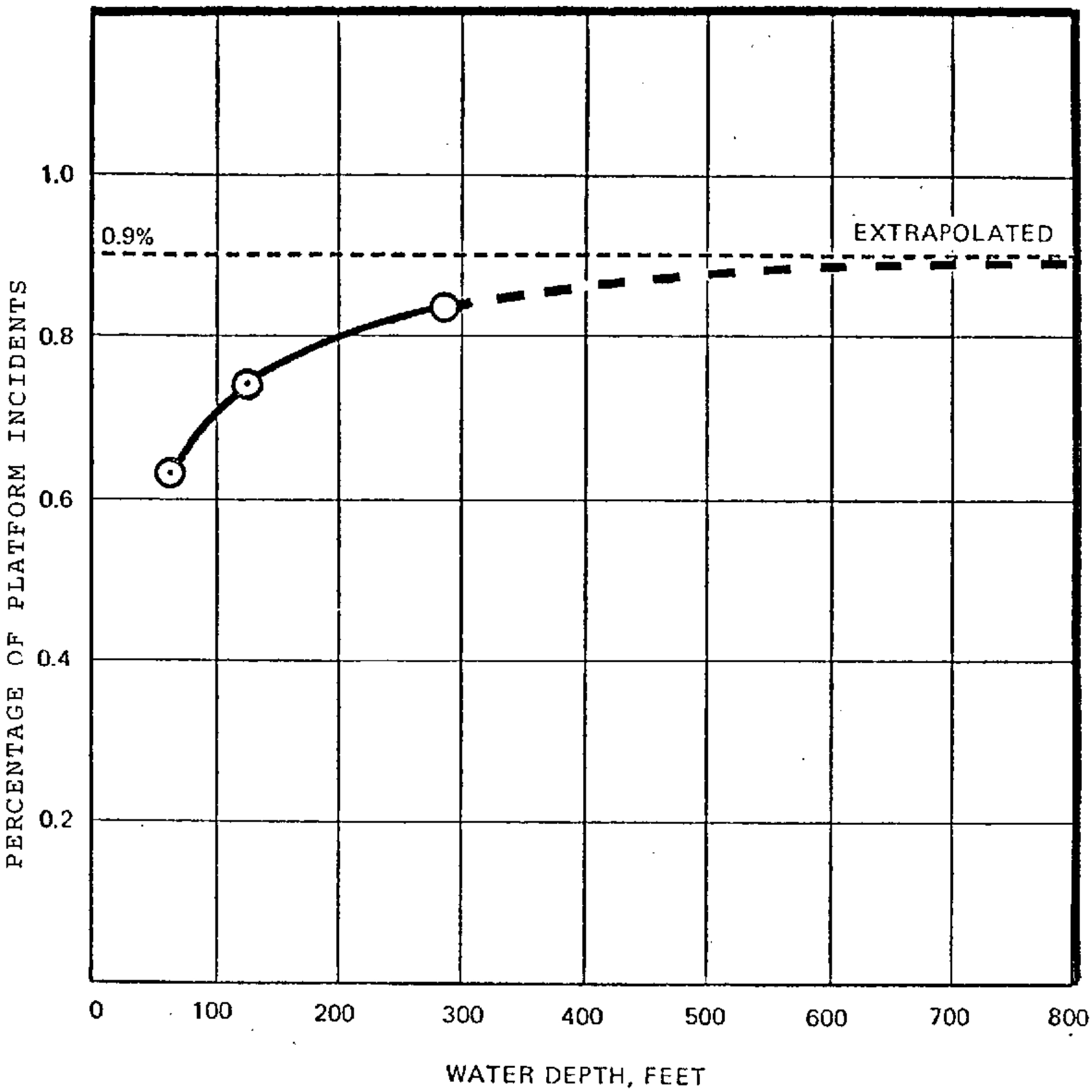

Figure 8.4 Shell Oil Platform Damages and Losses in Gulf of Mexico Experience Period 1955-1971

experience in the Gulf of Mexico. As extrapolated, the risk factor is tending to 9×10^{-3} during a time interval from 1955-1971, i.e., a period of 16 years. The average annual risk factor is, therefore, 6×10^{-4}. Marshall* uses 13×10^{-4} for an annual average risk rate based on a more sophisticated study of structural jacket, pile, and marine soil safety factors, plus 100 year frequencies of differently ranked storms. Marshall's analysis is based on statistical wave loading and platform reliabilities.

A representative annual risk factor is then 10^{-3}, assumed for the moment to be independent of the depth of water in which operations are occurring. This implies the loss of one rig or platform out of every 1,000 rigs or platforms operating in one year anywhere in the world due to an inconsistency between the rig or platform design and its operating environment characteristics.

Current cost for an average rig is $15.4 million. In 1985, the number of production rigs will lie between 163 and 1,300 and, conservatively, the number of drilling rigs may be about 700.

Thus, the inconsistency between design and environmental demand may result in an expenditure of $15 million to $30 million dollars, per annum, i.e., one or two rigs or platform being lost per year due to unexpected ocean conditions.

It is assumed that this expenditure is equally attributable to two factors; namely, the structural design process (including materials, and procedures) and a lack of knowledge of the operating environment, then today's lack of

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* Marshall, P. W., "Risk Evaluations for Offshore Structures", Journal of the Structural Division, Proceedings of the American Society of Civil Engineers, December 1969.

information concerning weather and ocean conditions is responsible for \$7.5 million to \$15 million per annum.

To attempt to relate the improvement in the prediction of weather and ocean conditions as a function of time of SEASAT's data input, the following tabulation is suggested as representative of the change in prediction capability.

Year	Instrumentation	Weather Knowledge Quality	Weather Ignorance Factor	Expenditure Associated (\$ Million)
1974	NO SEASAT	20%	80%	7.5 - 15.0
1985	NO SEASAT	28%	72%	5.4 - 10.8
1985	WITH SEASAT	60%	40%	3.8 - 7.5
2000	WITH SEASAT	80%	20%	1.9 - 3.8
?	WITH SEASAT	100%	0%	0

The tabulation of associated expenditure assumes that expenditure is a linear function of the weather knowledge factor.

From this Table, SEASAT's capability in 1985 will reduce expenditures by \$1.6-\$3.3 million (1974\$) and this is, therefore, the estimated cost savings in rig and platform design due to SEASAT in 1985.

Between 1985 and the year 2000, assuming a linear improvement in weather and ocean condition prediction, and a linear dependence of expenditure on the predictive ability, SEASAT's influence can be stated as follows, for the cost savings rig and platform design.

<u>Lower bound</u> 1.6 + 2 (y-1985)/15 \$ million (1974\$)

<u>Upper bound</u> 3.3 + 3.7(y-1985)/15 \$ million (1974\$)

when y is the year being considered.

8.2.5 Summary of the Results of the Generalization

8.2.5.1 The North Sea Generalization

The cost savings to North Sea oil production in 1985 due to the application of SEASAT data is estimated to be as follows:

From Accident Avoidance Savings	\$ 6.4 million
From Pipe Laying Labor Savings	\$10.7 million
From Derrick Barge Labor Savings	\$ 1.5 million
Total Cost Savings (1974%)	\$18.6 million

The estimated North Sea oil production in 1985 and the number of production platforms allocated to it to obtain the quoted cost savings require a 250,000 barrel of oil per day production per platform. This figure is about 2.5 times the generally acceptable platform production capacity. It is, therefore, suggested that the North Sea oil production cost savings could reach, in 1985, \$46 million (1974\$).

These cost savings are estimated to be durable until the year 2000, at least.

8.2.5.2 Offshore Oil Production in the Rest of the World

The annual cost savings for offshore oil production in the rest of the world due to SEASAT's data are estimated to be between \$85.6 million and \$214 million (1974\$).

These cost savings are estimated to be also durable until the year 2000, at least.

8.2.5.3 Conjectured Worldwide Offshore Oil Production

If U.S. oil production policy sought to replace Persian Gulf offshore oil by offshore oil from the Gulf of Alaska and the Eastern United States uniformly from 1974 to the year 2000, then the SEASAT benefit could be, it is estimated, from \$325 million to \$813 million (1974\$).

8.2.5.4 Drilling Rig and Platform Design

SEASAT data in 1985 will result in a reduction of expenditures for rig and platform replacement lying between \$1.6 million and \$3.3 million (1974\$).

Between 1985 and 2000, this reduction in expenditure is estimated to grow according to the following formulae in \$ million (1974\$).

Lower bound 1.6 + 2 (y-1985)/15

Upper bound 3.3 + 3.7(y-1985)/15

where y is the year being considered.

8.2.5.5 Benefit Dependence on Oil Parameters

More precise evaluation of these benefits requires an economic interpretation of the growth of exploitation in offshore oil production, development and exploration. This growth is evidently dependent on the world wide demand for oil, the price of oil and the requisite production to oil reserves ratios derived in each offshore oil field. The mechanisms by which cost reductions are produced in each of these operations will have to be determined for appropriate weather and Sea State forecasting quantity.

A careful evaluation of the application and implementation of contemporary technology of rig and platform design will also be required. This technology will be specifically applied to operating structures in violent or icebound sea and weather conditions and is expected to influence operating cost savings.

These evaluations with the help of user groups will be made during the next phase of this economic assessment.

9.0 MILITARY BENEFITS

9.1 Overview of Military Applications

The study of the relationship between military applications and the economic payoff of SEASAT began within various activities of the Department of Defense (DOD) during May, 1974 and will be completed in January 1975.

The results to date indicate a one-time cost-effectiveness benefit of $30.3 million attributable to SEASAT-A based upon DOD estimates of the cost of an equivalent capability.

Improved typhoon tracking and warning with an operational SEASAT system will provide an operational benefit of approximately $3 million per year.

Other significant operational benefits are expected in the areas of optimum track ship routing wartime operations and Polar Operations Support. The economic benefits of these and other military applications will be examined in on-going DOD studies.

Quantification of potential military benefits from SEASAT data requires both the definition and the weighting of evaluation criteria. Weighting of the criteria is related to a sequence of research, development, training, field support, and operational mission prosecution. Further, in many cases potential benefits from the SEASAT-A experiment will be realized only after the operational implementation and utilization of the techniques involved.

9.1.1 Research and Development Applications

Measurements of surface wind, significant wave height, and directional wave spectra by SEASAT-A will be used to evaluate operational capabilities for global prediction of directional wave spectra. Results from the operational demonstration phase of the SEASAT-A experiment will contribute to the definition of communications and data processing requirements necessary to sustain operational support products.

Experimental comparison of the capabilities of the multifrequency passive microwave radiometer and the active microwave scatterometer for determination of surface winds will permit cost, weight, power, and performance tradeoff decisions for definition of a subsequent operational system.*

Radar altimetry measurements from SEASAT-A will provide data for determination of the marine geoid for application to guidance problems involving inertial navigation systems. In order to achieve the design goal of 10 cm measurement precision, it will be necessary to use the full measurement capability of SEASAT-A to determine the effects of tides, current, sea-state, atmospheric propagation, and storm surges upon measurement of the local geoid.

SEASAT-A data will be used as an input to basic- and applied-research projects directed toward development of improved fleet support capabilities. Areas of application include analysis and prediction of:

- marine wind fields and directional wave spectra on a global scale;
- ocean tides;
- global circulation models;
- distribution, circulation dynamics, and deformation mechanics of sea ice and icebergs;

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*Program financial constraints may preclude this.

- surf, tides, storm surges, and littoral currents as related to design and maintenance of coastal structures and near-shore operations.

9.1.2 Operational Support of DOD Missions

Environmental analysis and prediction products, and an operational oceanographic measurement capability that can be derived from the SEASAT-A experiment, will have application to a wide range of DOD activities. A functional hierarchy may be listed as:

- Basic Research
- Advanced Development
- System Analysis
- Weapon System Design
- Operational Evaluation
- Personnel Training
- Logistics/Operational Support
- Operational Mission Effectiveness

While SEASAT-A may establish the technical feasibility of using a satellite system to acquire data to support these activities, the attainment of operational benefits will require a committment to provide continuity of data through an operational system.

Measurement and analysis products required for support of basic research, advanced development operational evaluation, personnel training, and logistics support are similar to those needed by the civil sector. Research, development, and evaluation efforts require precise documentation of existing environmental conditions for description and analysis of system performance. Quantification of benefits in these areas is difficult, and depends upon assessment of the operational return from the results of the research and development activities. However, in selected cases, such as acoustic research in the marginal ice zones, an operational SEASAT which provides an all-weather meso-scale measurement capability would be more cost-effective than aircraft for acquisition of similar data over prolonged periods (e.g. support of specific experiments and determination of seasonal variability of environmental conditions).

Similarly, it is difficult to place a simple cost value on returns from support of systems analysis, weapons systems design, and evaluation of operational mission effectiveness. In this area, functional performance is the evaluation criterion, and costs must be considered in a relative sense. Evolutionary development of advanced systems dictates that there shall always be a mix of operational capabilities. New systems may, in general, be characterized as being faster and having longer range than the older systems. Thus, the new systems have a different response function to the time- and space-scales of environmental variability. Therefore, there is a need to acquire a new synoptic oceanographic data base to support analysis, design, and effectiveness evaluation of operational options available to achieve functional performance. An example of this problem is the difference between Optimum Track Ship Routing (minimum time/no damage) for logistic support and Convoy Routing under conditions of Opposed Transit during a period of hostilities.

As indicated above, a third class of benefits may be identified which fall under the category of routing operational support. This area includes logistics support (ship routing) and scheduled operations such as personnel training exercises. Returns in this area (which is similar to scheduled civil operations) may be addressed in terms of simple cost savings.

9.2 Preliminary Results and On-Going Studies

The following information provides examples of types of economic payoff anticipated from the SEASAT-A experiment and from subsequent operational systems. The examples selected are not intended to provide a comprehensive statement of expected military benefits, and are preliminary estimates drawn from DOD studies now in progress.

9.2.1 Geodetic Data

The improved geodetic data derived from SEASAT-A radar altimetry measurements will be of major importance to the operational capabilities of vehicles using inertial navigational systems. A true benefit cost study of the SEASAT-A applications to geodesy will not be conducted, since the major impact will be in the area of strategic systems. However, as a measure of potential usefulness of SEASAT-A geodetic data to DOD programs, a cost effectiveness of $30.3 million (1975 dollars) has been assigned to SEASAT-A. This is based on an estimate of the cost to DOD to implement a dedicated satellite (with program startup in 1975) that would acquire the geodetic data expected from SEASAT-A.

9.2.2 Typhoon Forecast Improvements

A study of the Cost Effectiveness of Typhoon Forecast Improvements (carried out by S. Brand and J. W. Blelloch

U.S. Navy Environment Prediction Research Facility) was completed in May 1974. Benefits considered in this study included savings in transit time for ships re-routed to avoid typhoons, reduction of cargo damage by re-routing ships, and cost reductions that result from decreases of advanced preparation efforts that result from more accurate typhoon forecasting. Costs for preparation of a harbor depend upon the number and class of ships that must be moved, the direction and distance of the storm center relative to the port, and the warning time required to permit the ships to move to a safe refuge by the time of arrival of the typhoon. Costs related to evacuating aircraft and preparing an air base in advance of a typhoon are estimated to be approximately $300K in the Pacific. The Typhoon Cost Effectiveness study considers the benefits from potential improvement of typhoon forecasting over present capabilities. Benefits are determined for the bounded problem of typhoons only (not other large storm systems) in the Western North Pacific Ocean. Improved measurements of the typhoon intensities such as would be provided by an operational oceanographic satellite are necessary to realize the potential benefits. For the limited case described, involving improved forecasting of approximately 35 typhoons per year, cost savings are indicated to be approximately $3M per year. As a result of the greater degree of management control exercised in military organizations (as compared to civilian operators) these operational benefits will be considered to accrue beginning in the year following the launch of SEASAT-A.

9.3 Optimum Ship Routing

The concept of optimum ship routing based upon ship characteristics and forecasted weather data is currently used by the U. S. Navy to improve logistic operations. A Navy Optimum Track Ship Routing Cost-effectiveness survey conducted for the year 1970 indicated an average annual savings of $5,710,000 per year through the use of optimum ship routing. This study was based upon the routing of an average of 2717 ships per year in the Pacific and 817 in the Atlantic, using average ship operating costs of $10,000 per day, and a fuel cost of $2.00 per bbl. Current data indicates that Pacific routings have decreased to about 1000 per year, while Atlantic routing have increased slightly. In the same period of time ship operating costs (for logistics ships) have more than doubled, while fuel costs have increased to approximately $10.00 per bbl. On the basis of this partial data, it would appear that the magnitude of the benefit to the Navy of optimum ship routing for logistics ships has increased in the face of declining operations. In many respects the Navy Ship Routing problem for logistics ships is similar to the civilian ship routing problem. For this reason, it is fully expected that additional benefits can be obtained in this area as a result of improved ocean condition forecasts using SEASAT data. It is anticipated that on-going Navy Studies will provide an estimate of this incremental benefit attributable to SEASAT data and will include high speed container ships, and surface effects ships.

Since Navy requirements during periods of national emergency or wartime often require the routing of ships as a function of operational considerations into regions not served by conventional shipping lanes, it is considered that the global data gathering capability of an operational SEASAT system will provide an important extension of Navy capability for optimum ship routing.

9.4 Operations In A Wartime Environment

Two additional studies are being conducted that are broader in scope than the purpose of the SEASAT program. These studies will serve as sources for specific cost effectiveness information in certain areas. The first study relates to Ocean Science in Inshore Warfare, and is being conducted by LCDR Dorman and Mr. Tolbert of the Naval Coastal Systems Laboratory, Panama City, Florida.

10.0 SUMMARY OF BENEFITS

The benefits presented as a result of this study have been developed from very specific case studies. A case study, while it is a study in depth, is thought of as a sample from a larger population. However, within the case study, many alternative mechanisms for producing potential benefits can exist and, in general, not every such mechanism is investigated. Thus, it is emphasized that a case study tends to focus only on certain of its benefit producing mechanisms and, hence, is only a partial accounting of the benefits possible within the case study operation.

The case study is itself selected from a population of operations that appear on the basis of preliminary examination, to be capable of generating benefits. Here the focus is on estimation of the magnitude of the benefit generating possibilities, and on the potential for acquiring the necessary data from which quantitative results can be developed within the time and budget available.

A set of completed case studies represents, therefore, almost always, a very partial accounting of benefit producing operations and benefit producing mechanisms within these operations. Because of this it is not possible, subsequent to the development of the case study results, to estimate what fraction of the total possible benefits have been evaluated.

The case study generalization undertakes to extend the specific case study quantitative results into the population of which the case study is a sample. This extension must be appropriately delimited by controls which are either technological or economic in content, but which must also be projected to an appropriate time or planning horizon. The projection must also be controlled, with controls that are either economic or technological. For example, by generalization, it has been possible to extend the results of a case study of offshore oil production in the North Sea to the global production of offshore oil in the year 2000.

In selecting the case studies several promising application areas that were suggested by the survey of uses and users were not investigated. Examples of these prospective benefit areas are:

- improving the productivity of the ocean fishing industry
- providing improved design criteria for and monitoring the operation of offshore permanent structures such as nuclear power plants
- establishing design criteria to minimize destruction of beaches and coastal zones caused by weather and ocean conditions
- ocean mining or resources other than oil and natural gas.

As was stated in Section 9.0, the estimate of military benefits is both preliminary and incomplete. When a detailed analysis of military benefits is completed in 1975, it is fully expected that additional military benefits associated with the operational SEASAT will emergy. The military benefits identified in this study are primarily associated with SEASAT-A. Moreover, although no current benefits have been determined from the ports and harbors case study, this result is based solely on qualitative information. Several industry representatives have indicated that significant costs are frequently incurred because of ETA's missed either through weather and ocean induced conditions, or as a result of inadequate prediction of the weather, but the statistical data needed to perform a quantitative analysis was not available because it is not generally collected by the agencies or organizations contacted during the case study.

A complete assessment of SEASAT economic benefits must consider the influence of improved ocean condition and weather forecasts on land based operations. It is fully expected that improved ocean condition data will lead to more accurate long range weather forecasts for land regions. The economic benefit of improved long range weather forecasts on land based operations such as agriculture, construction, recreastion, and transportation has not been considered in this assessment.

It is concluded, therefore, that the estimated aggregated SEASAT benefit produced by this study is both preliminary and partial. When benefit producing operations or mechanisms are analyzed or evaluated, the data employed is seldom substantive, particularly when projection is required. Alternative values of the benefits can generally be determined. In this study it has been the policy to choose value magnitudes which will produce the smaller benefits so that the reported benefits are conservative.

Table 10.1 summarized the benefits from SEASAT dervied in this study. It must be emphasized that these benefits are preliminary and partial, and to a great extent conservative estimates.* The values of the annual benefit are shown in Table 10.1 in 1974$, as are the aggregated benefits. The aggregated benefits are the columnar sums of the present value of annual benefits at different discount rates.

Figure 10.1 shows the lower bound (or minimum) accumulated benefits as a function of time with discount rate as a parameter.

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* Shown in Table 10.1 are both the <u>lower</u> and <u>upper</u> bound estimates of the present value of the benefits of 1974$.

Table 10.1 Lower and Upper Bound Estimates of Benefits (in millions of 1974$) Planning Horizon to 2000

	Discount Rate							
	0%		5%		10%		15%	
	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound
Ship Routing	578	578	243	243	110	110	52	52
Iceberg Reconnaissance	194	59	78	24	36	11	20	6
Canadian Arctic Operations	1932	1273	959	595	435	270	223	138
Alaska Pipeline	66	66	26	26	13	13	7	7
Off Shore Oil Production	3477	1395	1450	580	660	264	325	130
Military	78	78	44	44	28	28	19	19
Aggregate Benefits	6325	3449	2800	1512	1282	696	646	352

Figure 10.1 shows the <u>lower</u> bound (or minimum) accumulated benefits as a function of time with discount rate as a parameter.

The present value is obtained from the relationship:

Present value at the end of 1974 equals:

$$\sum_{Y=1975}^{Y=2000} \frac{(\text{Annual Value (1974\$)})_Y}{(1 + \text{Discount Rate})^{Y-1974}}$$

where

Y = the year in which the benefit is acquired, the time of acquisition assigned being the end of the year Y.

A planning horizon extending from 1974 to the year 2000 has been used. Three discount rates of 5%, 10% and 15% were selected to illustrate the variation of the aggregate benefit with discount rate.

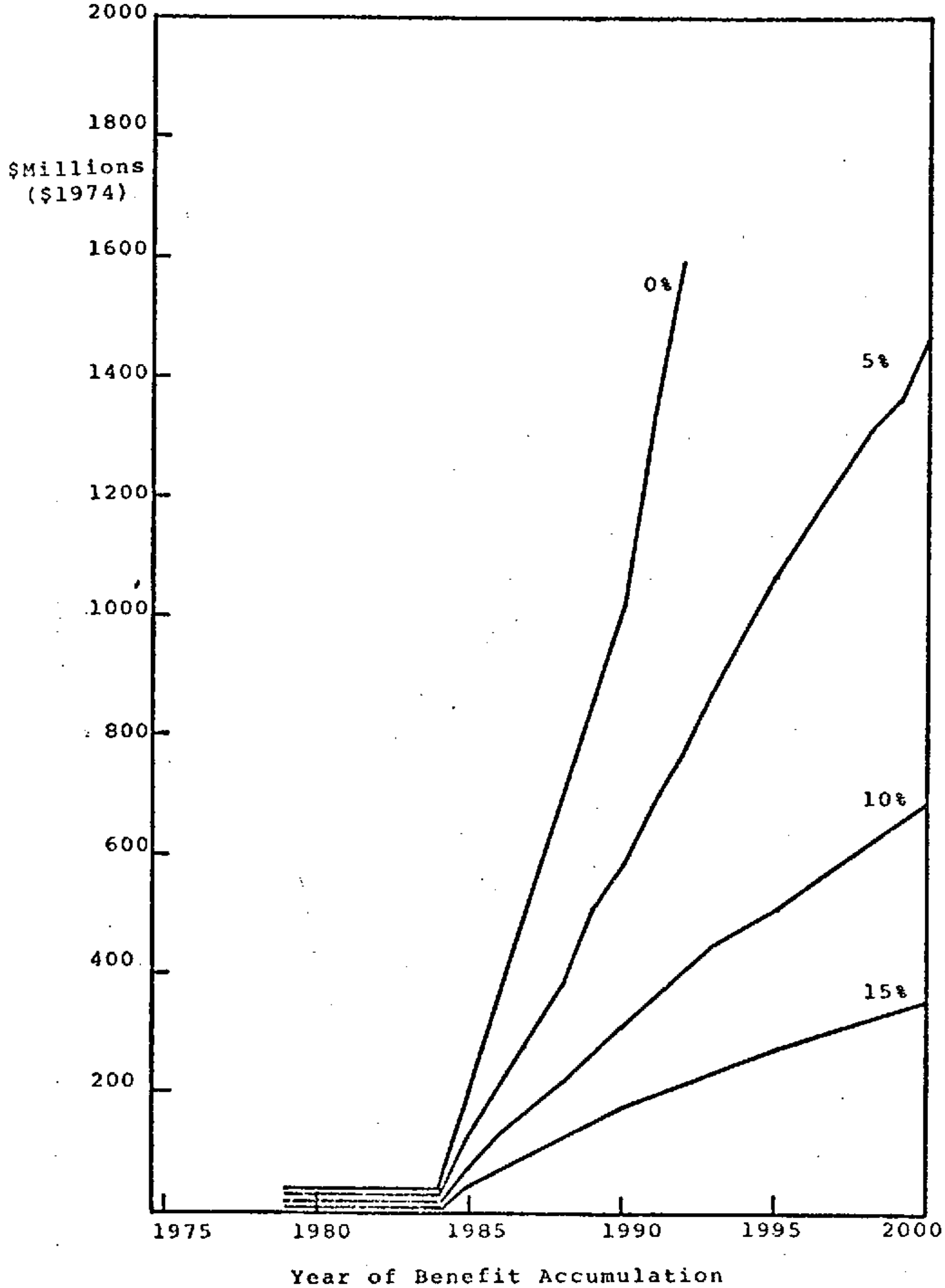


Figure 10.1 SEASAT Minimum Accumulated Benefits (1974$) With Discount Rate as Parameter

GLOSSARY OF TECHNICAL MARITIME TERMS

AND ECONOMIC TERMS

Average Freight Rate Assessment - is a method of assessment for charging freight which is being increasingly used by major oil companies. It became obvious in the early 1950s that to base freight charges on single voyage market rates was unfair, especially to large long-term customers. The London Tanker Brokers Panel provided an assessment, calculated according to specific terms of reference, of the average rate at which all vessels over 10,000 t. summer deadweight were operating on commercial charter during a given period. The terms of reference are revised from time to time when developments within the tanker industry necessitate changes. At present AFRA is published on the first of each month and the assessment relates to vessels on charter and in service during the month terminating on the fifteenth day of the previous month, e.g. AFRA published 1st October relates to vessels in service during the period mid-August to mid-September (from OECD [145, p. 135]).

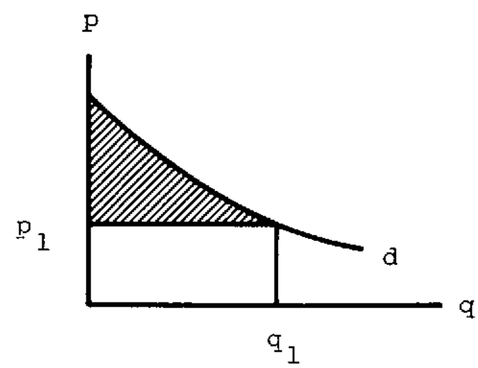
Barrel (bbl.) - 31.5 gallons (1 barrel ≅ 300 lbs.)

Combination Passenger and Cargo Ships - ships with a capacity for 13 or more passengers.

Consumer's Surplus - is the difference between the price a consumer actually got paid for a good and the price he would have been willing to pay rather than do without the good. If we know the consumer's demand curve and the quantity he actually purchased we can calculate his total consumer surplus as

$$\int_0^{q_1} f(q_1)\,dq_1 - p_1 q_1$$

which is illustrated as the shaded area in



Container Vessels - ships designed to carry intermodal containers of cargo to be loaded to and from trucks.

Deadweight Tons (dwt) - usually presented as the payload in long tons to a certain draft when speaking of a ship's carrying capacity. (1 dwt $\cong$ 7.47 barrels.)

Deflating - see "discounting"

Demand Curve - The demand curve of a single consumer represents the quantity he will buy as a function of its price. This demand curve is derived by analysis of the consumer's utility optimization behavior. If his satisfaction or utility (U) depends on how much of, say for example, two goods (q_1 and q_2) he obtains and he has a budget (M) and is faced with certain prices (p_1 and p_2) we get, as an example,

$$U = q_1 q_2 \quad \text{and } M = p_1 q_1 + p_2 q_2$$

which yields a Lagrangian constrained expression

$$U' = q_1 q_2 + \lambda(M - p_1 q_1 - p_2 q_2)$$

and this gives first order conditions with three equations and three unknowns

$$\frac{\partial U'}{\partial q_1} = q_2 - p_1\lambda = 0$$

$$\frac{\partial U'}{\partial q_2} = q_1 - p_2\lambda = 0$$

$$\frac{\partial U'}{\partial \lambda} = M - p_1q_1 - p_2q_2 = 0$$

which yields the two demand functions sought.

$$q_1 = \frac{M}{2p_1} \text{ and } q_2 = \frac{M}{2p_2}$$

As expected we find demand inversely related to price (and directly related to income).

Discounting - is the process of adjusting monetary values to reflect their time value. Since a dollar of profit or consumption is not as valuable one year hence as it is now we must adjust future flows downward ("discount") to determine their present value. This process should not be confused with deflating which is not a substantive adjustment like discounting but only a scale adjustment in our yardstick--prices. An example may be useful to illustrate:

	Year 1	Year 2	Year 3	Year 4
Revenue (current $)	$783	912	1072	1189
Price Index	1.00	1.07	1.15	1.20
Revenue (Constant $)	$783	852	932	991
Discount Factor (10%)	1.00	.909	.826	.751
Present value of each year's revenue (or Discounted-cash-flow)	783	774	770	744
Cumulative Discounted Cash Flow	783	1,557	2,327	3,071
Present Value, Total	3,071			

The corresponding formulas are

$$\text{Revenue (Constant \$)} = \frac{\text{Revenue (Current \$)}}{\text{Price Index}}$$

$$\text{Present Value, Total} = \sum_{1}^{\text{last year}} \frac{\text{Revenue (Constant \$)}}{(1+\text{Discount Rate})^{\text{Year}-1}}$$

Dotto - Department of Transportation Transoceanic (codes). Ship classification.

Draft (in feet) - the depth to which the vessel extends below the surface.

Dry Bulk Vessel - carries cargo such as grain, ore, sugar, etc.

Elasticity - is defined as a ratio of percentages: the precentage change in one variable relative to the percentage change in a second variable. For example, the elasticity of the quantity demanded to price is given symbolically by

$$\epsilon = \frac{\frac{q_1 - q_o}{q_o}}{\frac{p_1 - p_o}{p_o}} = \frac{\frac{\Delta q}{q}}{\frac{\Delta p}{p}} = \frac{\text{\% change in quantity demanded}}{\text{\% change in price}}$$

When $|\epsilon| < 1$ we say the quantity demanded is inelastic, or insensitive, to price changes; when $|\epsilon| > 1$, we say the demand is elastic; and when $|\epsilon| = 1$, we have "unitary" elasticity. Other commonly used elasticities are the elasticity of the quantity supplied to price and the elasticity of quantity demanded to income. When we speak of the demand or supply elasticity we mean relative to price unless stated otherwise.

By the calculus, elasticity can also be defined at a point on the demand curve as the product of the first derivative and the ratio of the price to the quantity at that point:

$$\epsilon = \frac{dq}{dp} \times \frac{p}{q}$$

Econometric Model - is a mathematical statement of economic relationships which employs statistical methods. An econometric model may be one equation or a system of equations. There are four steps in the implementation of an econometric model:

1. Specification - Mathematical statement of the economic theory (one equation or a system)
2. Estimation - Statistical estimation of the coefficients in the mathematical statement.
3. Verification - Evaluation by theoretical and statistical criteria of estimation results.
4. Prediction - Use of the verified model by solving for future values.

Thus, econometric models are a subcategory of mathematical models which utilize statistical procedures to estimate the coefficients in the mathematical model of an economic relationship.

Endogenous Variable - Variables solved for in the mathematical model (as opposed to exogenous variables whose values are fed into the model and are used to solve for the values of the endogenous variables).

Should not be confused with dependent and independent variables. A dependent variable (or independent variable) may be endogenous or exogenous. For example, in a function with one dependent variable and one independent variable we may know either of these (the exogenous variable) and solve for the other (the endogenous variable).

Exogenous Variable - see "endogenous variable"

f.o.b. - free on board.

f.i.o. - free in and out.

c.i.f. - cost, insurance, freight.

Freighters - includes containerships, car carriers, roll-on-roll/off and LASH ships.

Inelastic - see elasticity.

Knots - nautical miles per hous (1 nautical mile = 1.1508 statute miles).

LASH Vessel - (Lighter Aboard Ship) capable of carrying a combination of barge and containers.

Liners - a vessel which follows a regular route and schedule.

Liquid Bulk Carrier Vessel - carries cargo such as oil or chemicals.

Long Ton - 2,240 lbs. (= 1.016 metric tons).

Maritime Industry - encompasses all ocean going activities as opposed to inland waterway activity.

Metric Ton - 1,000 kilograms (=2,204.724 lbs.)

Short Ton - 2,000 lbs. (= .907 metric tons).

Tanker - vessel that usually operates by charter over a long term period; includes: molten sulphur tankers, chemical tankers, liquified petroleum and natural gas tankers, and whaling tankers.

Tonnage

Barrel (bbl.) - 31.5 gallons (1 barrel ≅ 300 lbs.)

Deadweight Tons (dwt) - usually presented as the payload in long tons to a certain draft when speaking of a ship's carrying capacity. (1 dwt $\cong$ 7.47 barrels.)

Long Ton - 2,240 lbs. (= 1.016 metric tons).

Metric Ton - 1,000 kilograms (= 2,204.724 lbs.).

Short Ton - 2,000 lbs. (= .907 metric tons).

Tramp - opportunist vessel which takes what cargo is available and does not follow a fixed schedule.

Transport Homogenous Groups (THG's) - vessels typed according to the commodity they carry.

ULCC - Ultra Large Crude Carrier, i.e. tankers over 250,000 deadweight tons.

VLCC - Very Large Crude (oil) Carrier, i.e. tankers between 100,000 and 250,000 deadweight tons.

Worldscale - is the code name for the freight scale currently in use in the world tanker market, the objective of the scale being to provide a yardstick which accurately reflects the relationship between one voyage and another on all voyages on which tankers ply. It was preceded by a two-schedule system, of which Instascale was more widely used and had been employed since 1962.

The rates are set by assuming a notional ship (19,500 t. summer deadweight) with certain performance characteristics and a fixed charter cost per day as factors to calculate the cost of carrying a ton of oil on this vessel on a particular voyage. All the basic rates are calculated on the same basis and a "Schedule" is build up. By this means the Worldscale schedule of freight rates provides a basic freight rate for every voyage which tankers are able to perform on a comparable basis. It supplied the mechanism for the working of the tanker market and a convenient framework for the evaluation of all aspects of freighting costs and charges. (From OECD [145, p.135]).

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APPENDIX A

COMPARISON OF DAILY PROGRESS REPORTS AND INDEPENDENT WEATHER REPORTS FOR THE CONSTRUCTION OF A 38-MILE PIPELINE AND 3 PRODUCTION PLATFORMS IN THE SOUTHERN NORTH SEA

The progress reports were provided on a not-for-attribution basis and, accordingly, are not identified as to location or exact year. The time is before 1971.

Symbols

W	=	Work at offshore site
WL-95	=	Work Laying pipe - 95 sections welded (Section is 40 ft long)
H	=	Hold at offshore site due to weather
T	=	Towing barge to or from work site
P	=	in Port due to weather
A	=	Accident seriously affecting work
R	=	Repairs to main work barge or pipeline
6'	=	6 foot seas
30 kts	=	30 knot winds
1/2	=	slight seas
*	=	A serious discrepancy between Progress Reports and Weather Reports
	=	Double Underscore indicates Days Lost to Accident
	=	Single Underscore indicates potential savings for pipeline barge if weather forecasts were reliable
	=	Underscore indicates potential savings for derrick barge if weather forecasts were reliable

COMPARISON OF DAILY PROGRESS REPORTS WITH WEATHER REPORTS AS OF 0600

Date	July 4	July 5	July 6	July 7	July 8	July 9	July 10	July 11	July 12	July 13	July 14	July 15
Barge Report	WL-24 Start Offshore	WL-45 A	WL-14 R	WL-20	WL-83	WL-68	WL-63	H Storm	H Storm	WL-74	WL-23 A	R
Weather Report	1'	1/2	1/2	1'	1/2	1/2	1/2	6'	5'	1'	1/2	2'

Accident Not Weather Related

Stinger Damage Acknowledged to be due to preceeding storm

Date	July 16	July 17	July 18	July 19	July 20	July 21	July 22	July 23	July 24	July 25	July 26	July 27
Barge Report	R	R	R	R	T	W	WL-25	WL-92 Supply Transfer	WL-68 Unsafe	WL-79	WL-30	WL-103
Weather Report	12'	3'	3'	1'	1'	2'	3'	4'	3'	3'	3'	1'

Date	July 28	July 29	July 29	July 30	August 1	August 2	August 3	August 4	August 5	August 6	August 7	August 8
Barge Report	WL-111	WL-124	WL-122	WL-104	WL-63	WL-45	WL-61	WL-60 Testing	WL-101	WL-40 A	Storm R	Storm R
Weather Report	1'	1'	1'	2'	3'	3'	3'	1'	3'	3'	8'	8'

Stinger & Pipe Damage Due to Lack of Warning

Date	August 9	August 10	August 11	August 12	August 13	August 14	August 15	August 16	August 17	August 18	August 19	August 20
Barge Report	Storm R	Storm R	R	R/W	R/W	R/H	R/H	R/H	R/H	R/W	R/W	R/W
Weather Report	6'	4'	3'	3'	1'	1'	2'	3'	3'	1'	3'	1'

Burry Barges Only During (R/W) Period

Accident days not counted as significant progress was made by trenching barges

TOTAL DAYS 48 - Accident days 11

COMPARISON OF DAILY PROGRESS REPORTS WITH WEATHER REPORTS AS OF 0600

Date →	August 21	22	23	24	25	26	27	28	29	30	31	September 1
Barge Report	R/W	T/W	W Platform deck & derrick barges leave port →	W	W	W	H Arrive site	H	H	H	H	Deck placed in 30 min
Weather Report	1/2 Progress by trenching barges	1/2	1/2	1'	3'	3' (2 Derrick barges)	3'	3'	5'	6'	3'	2'

Date →	September 2	3	4	5	6	7	8	9	10	11	12	13
Barge Report	WL-26	WL-30 Pipe buckle	W	W	W	W	WL-81	WL-100	WL-81	WL-132	WL-109	WL-131
Weather Report	3'	2' Pipe buckle "may" have been due to weather	1/2	1/2	1/2	1/2	1/2	1/2	1'	1/2	1/2	1'

Date →	September 14	15	16	17	18	19	20	21	22	23	24	25
Barge Report	WL-104	T 30 kts	P	P	T-W	WL-52	H Platform barges leave port	H	H	T	T	WL-40 Platform H
Weather Report	1'	2' 15 kts	18' 35 kts	12' 15 kts	6'	3'	5' 25 kts	7' 20 kts	6' 20 kts	6' (2 Derrick barges)	5'	5'

Date →	September 26	27	28	29	30	October 1	2	3	4	5	6	7
Barge Report	WL-40 Platform H	WL-131	WL-112	WL-99	T	WL-108 Platforms	WL-132	WL-120 Deck placed in 20 min	WL-128	WL-125 Deck placed	WL-70	WL-42 A
Weather Report	3'	5'	12' *	6'	4'	1/2	1'	1'	1/2	1/2	1/2	3'

TOTAL DAYS 48 - Pipe barge weather days 10 - Derrick barge weather days 11

COMPARISON OF DAILY PROGRESS REPORTS WITH WEATHER REPORTS AS OF 0600

Date →	October 8	9	10	11	12	13	14	15	16	17	18	19
Barge Report	W/R	W/T	R/W	R/W	R/W	R/H	R/H	T	H	H	H	W
Weather Report	1'	1/2	2'	3'	4'	12'	3'	2'	5'	14'	5'	1/2

Trenching Barges Only Work During (R/W)

Stinger Break Not Due to Immediate Weather Problems

Date →	October 20	21	22	23	24	25	26	27	28	29	30	31
Barge Report	WL-13	WL-126	WL-123	WL-132	WL-111	WL-111	WL-122	WL-139	WL-72	WL-100	WL-45 Main Pipeline Done	W
Weather Report	2'	2'	1'	1/2	1/2	1'	1/2	1'	2'	8' *	10' *	10' *

Date →	November 1	2	3	4	5	6	7	8	9	10	11	12
Barge Report	W/A	T Storm	P	T	H	T Storm	P	P	P	T	H	H/W
Weather Report	2'	15'	12'	10'	3'	10'	14'	12'	3'	3'	3'	2'

Date →	November 13	14	15	16	17	18	19	20	21	22	23	24
Barge Report	W	T 55 kts	P	P	P	P	T	W	W	H	H	W
Weather Report	4'	4'	8'	9'	5'	6'	6'	5'	3'	2'	2'	2'

TOTAL DAYS 48 - Pipe barge weather days 11

COMPARISON OF DAILY PROGRESS REPORTS WITH WEATHER REPORTS AS OF 0600

Date →	November 25	26	27	28	29	30	December 1	2	3	4	5	6
Barge Report	W	W	W	W-Test	W-Test	W-Test	W	W	W	W	W	W
Weather Report	3'	5'	2'	1/2	2'	8'	1/2	1'	2'	4'	3'	1'

Date →	December 7	8	9	10	11	12	13	14	15	16	17	18
Barge Report	W	No report "W"	"W"	W	W	W	W	W	W	W	W	W
Weather Report	2'	4'	2'	2'	2'	1/2	1/2	1/2	1'	2'	3'	6'

Date →	December 19	20	21	22	23	24	25	26	27	28	29	30
Barge Report W	W	H 13' 35 kts	H	H 18' 60 kts	T	T	T	H 20' 45 kts	H 22' 50 kts	H	H	W
Weather Report	2'	10'	8'	14'	9'	5'	3'	4'	12'	12'	10'	5'

Date →	December 31	January 1	2	3	4	5	6	7	8	9	10	11
Barge Report	W	W	W	W	W	W	W	H	H	W	W	H 45 kts
Weather Report	10'	6'	6'	3'	2'	1'	2'	4'	9'	3'	6'	4' 15 kts

TOTAL DAYS 48 - Pipe barge weather days 8

COMPARISON OF DAILY PROGRESS REPORTS WITH WEATHER REPORTS AS OF 0600

Date	January 12	13	14	15	16	17	18	19	20	21	22	23
Barge Report	W	H	H	Admin hold	Admin hold	H Squalls	H 25' 60 kts	H	W	H	Complete subtask T	T Tow to Clean up
Weather Report	4'	5'	8'	5'	3'	1'	8'	8'	4'	6'	2'	2'

Date	January 24	25	26	27	28	29	30	31	February 1	2	3	4
Barge Report	T Clean up tow	T/W	W	W	W	W	W	H	H	H	T	P
Weather Report	2'	3'	4'	4'	2'	5'	3'	18'	3'	20'	25'	14'

Date	February 5	6	7	8	9	10	11	12	13	14	15	16
Barge Report	T	W	W/T	H/T	H 25 kts	T	H	T	P 25 kts	T	W	No report "H"
Weather Report	3'	20' *	25'	14'	7'	5'	10'	20'	20' 25 kts	15'	8'	10'

Date	February 17	18	19	20	21	22	23	24	25	26	27	28
Barge Report	T	T	H/T	H	H/T/W	W	W/H/T	T/H 8' 20 kts	H	H	W	H
Weather Report	3'	3'	6'	18'	14'	6'	5'	12'	10'	8'	6'	6'

TOTAL DAYS 48 - Pipe barge weather days 27

COMPARISON OF DAILY PROGRESS REPORTS WITH WEATHER REPORTS AS OF 0600

Date →	March 1	2	3	4	5	6	7	8	9	10	11	12
Barge Report	H 10'	W 6'	W 8'	H 10'	W 5'	W 6'	W	W	W 8'	W	H 10'	H
Weather Report	5'	5'	6'	6'	3'	1/2	1/2	2'	4'	3'	2'	2'

Date →	March 13	14	15	16	17	18	19	20	21	22	23	24
Barge Report	H	H	H	H/T	P	P	T	W	H	H	W	W
Weather Report	6'	25'	14'	20'	20'	24'	28'	16'	8'	10'	8'	5'

Date →	March 25	26	27	28	29	30	31	April 1	2	3	4	5
Barge Report	W	W	W	W	W	W	W	H Tow Pipe Barge for Demobilization	H	W	W	W
Weather Report	4'	3'	2'	1/2	1'	2'	3'	25'	18'	8'	2'	1/2

Date →	April 6	7	8	9	10	11	12	13	14	15	16	17
Barge Report	H 12'	H/W	W	W	W	W/H	T	P	T	H 12'	H	H Test
Weather Report	3'	3'	1/2	1'	2'	2'	6' 25 kts	12'	14'	15'	22'	20'

TOTAL DAYS 48 - Pipe barge weather days 8

COMPARISON OF DAILY PROGRESS REPORTS WITH WEATHER REPORTS AS OF 0600

Date	April 18	19	20	April 21								
Barge Report	H-Test	T/P	No Further Progress Reports Available									
Weather Report	15'	12'	4'	6'								

Date												
Barge Report												
Weather Report												

Date												
Barge Report												
Weather Report												

Date												
Barge Report												
Weather Report												

TOTAL DAYS 2

APPENDIX B

APPLICATIONS OF THE GEOID AND THE ROLE OF THE SATELLITE ALTIMETRY

by

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on

CIVIL APPLICATIONS OF THE GEOID VOLUME II: APPLICATIONS OF THE GEOID AND THE ROLE OF SATELLITE ALTIMETRY

INTRODUCTION

As a preamble to detailed discussion of the subject matter, the geoid is defined, its various scientific and practical applications are outlined, conventional methods and associated problems in practical determination of the geoid are described, and the necessity for resorting to satellite altimetry for geoid determination is explained. The focus centers on clarification of the foremost problems that must be addressed before practical realization of satellite altimetry applications to geoid determination can be achieved. Finally, various uses of the satellite altimeter determined geoid are described.

Perhaps one of the most economically significant potential uses of the geoid is the synthesis of gravity anomalies (to be defined later) which can be used for various applications, including geophysical exploration for oil, gas, and other minerals. The theory and practical implementation of available approaches for synthesising gravity anomalies are described. Problems associated with such implementation are identified and their ramifications discussed, including performance criteria and achievable accuracy and precision requirements. Consequently, recommendations are made for investigations which would best contribute to achieving the goals of SEASAT with respect to the applications of the geoid. Preliminary calculations made in this study suggest that extremely precise altimetry will be required to permit useful synthesis of gravity anomalies from geoid measurement. However, more intensive investigation, as outlined, is required to obtain figures that can be quoted with confidence. It appears that accuracies on the order of several mgals in the synthesis of gravity anomalies from satellite altimetry can be achieved subject to the performance criteria discussed later. Skylab altimetry results [McCoogan, et al., 1974; Fubara and Mourad 1974] have demonstrated the feasibility of geoid determination from satellite altimetry with an rms relative height differences of about 1 meter (absolute error due to poor orbit ephemeins of Skylab is 10 to 50 meters dependent on geographical locality). GEOS-C and later SEASAT should improve on these results.

GENERAL CONCEPTS, APPLICATIONS, AND PROBLEMS

This section contains general conceptual definitions, practical and scientific applications of the geoid, problems of classical methods for geoid determination, the need for and the concept of satellite altimetry determination of the geoid, and associated general fundamental problems. A later section will deal with specific problems for specific applications of the satellite altimetry geoid. In the discussions of this text, for descriptive convenience, a distinction is made for the "continental geoid" (the portion of the geoid in continental areas) and the "marine geoid" (the portion of the geoid in the oceans).

The Geoid - Practical Definition

The geoid is that equipotential surface that would coincide with the "undisturbed" mean sea level of the earth's gravity field. "Undisturbed" mean sea level is the condition that would exist if the oceans were acted on by only the earth's gravity and by no other forces such as those due to ocean currents, winds, tides, atmospheric conditions, etc.

The geoid is an irregular surface that does not exactly conform to any known geometric figure. An ellipsoid of revolution is the geometric figure that best approximates the geoid. Consequently, the geoid is usually physically specified by giving the height differences of the geoid relative to a chosen reference ellipsoid. These height differences are called "geoid heights" or "geoid undulations." For the chosen reference ellipsoid, a uniform gravity field potential can be described mathematically. This is called theoretical or "normal gravity" and represents what the gravity field would be for a rotating ellipsoidal earth with uniform mass distribution. The actual earth has an irregular mass distribution and, hence, an irregular gravity field. At any given point, the difference between the actual measurable gravity value and the "normal gravity" is called the gravity anomaly, [Heiskanen and Moritz, 1967]. The conventional unit of gravity and its anomaly measurement is the "GAL": 1 gal = 1 cm sec^{-2}. The unit used in most practical work is the milligal (mgal) = 10^{-3} gal.

Applications of the Geoid

In addition to the various scientific and practical applications outlined below, the above definition of the geoid in combination with the already proven potential of satellite altimetry from Skylab data [Fubara and Mourad, 1974a; McCoogan,et al., 1974] leads to two very important practical results for oceanography and exploration geophysics. The important implication of this definition to oceanography is that knowledge of the geoid and the departures from the geoid of the sea surface topography due to non-earth-gravitational forces will lead to improved modeling of various ocean dynamics phenomena, such as currents, tides, circulation patterns, and, hence, air-sea interaction. The latter is an important input for improved numerical weather prediction. The "fine structures" of the geoid represent variations or irregularities of the earth's gravity field. These irregularities are largely caused by local mass anomalies in the earth's crust and therefore, their measurement has direct practical and economic benefits in geophysical exploration for locating geological structures associated with oil, gas, and other mineral deposits.

In general, three main categories of practical and scientific applications of the geoid can be specified. The basis for the categories is the data density and distribution, accuracy, and precision requirements for achieving the objectives of each class. They are

(1) Geophysical prospecting for oil, gas, and other minerals (this class is "exploration geophysics applications")

(2) Definition of reference datum necessary for oceanographic interpretations and applications of satellite altimetry for improved understanding and modeling of the physical phenomena and dynamics of the oceans (this class is to be called "ocean physics applications")

(3) Improved determination of the earth's gravity field for (a) satellite orbit computation, (b) missile trajectory computations and systems analysis, (c) determination of the figure of the earth - the size and shape of the geometric figure (reference ellipsoid) that best approximate the figure of the earth - the age old preoccupation of geodesy, (d) geodetic datum definition, centering, and orientation required in geodetic network calculations for control point establishment, surveying and mapping, which are required for economic and well organized exploration and exploitation of continental and ocean resources and for national defense operations, (e) definition of an unique equipotential datum for leveling operations, reductions of various geodetic and positional astronomy measurements, (f) improvement (via the computation of gravity anomalies and/or deflections of the vertical) of error control in inertial navigation systems,

(g) rectification of continental "geoids" for correct shape, scale, orientation, and centering (these are classified as "solid earth physics applications").

Conventional Geoid Methods and Problems

A detailed treatment of these matters is given in Fubara and Mourad [1972]. That text shows that, in spite of the exact definitions of the geoid, its determination with satisfactory scale, shape, orientation, and geocentering continue to be an elusive target, using conventional data theory and computational techniques. Table 1, taken from Fubara and Mourad [1972] is a summary of the methods, problems, and qualitative characteristics of the main conventional-type geoid determinations and how they compare with expected results using satellite altimetry. As used in the following table, "absolute orientation" implies that the major and minor axes of the geoid are parallel to the mean terrestrial equator and the mean rotational axis of the earth.

Besides the qualitative failures of the conventional geoid techniques, the required data accuracy and the need for worldwide (including the oceans) data collection imply such great expenses and political inhibitions that these conventional methods can never be expected to accomplish determination of the geoid required for all the practical applications outlined earlier. As a result, satellite altimetry is currently the sole means to remedy the situation, speedily, accurately and economically. The satellite altimeter programs of GEOS-C and SEASAT are, therefore, timely and should improve on the remarkable results already obtained from the Skylab altimeter program.

TABLE 1. COMPARISON OF CONVENTIONAL MARINE GEOIDS AND "SATELLITE ALTIMETRY GEOID" FOR COMPATIBILITY

Type of Geoid	Compatibility Criteria			Quality of Geoid and Sources of Deficiencies
	Absolute Orientation	Correct Scale	True Shape	
(1) Astrogeodetic (classical)	No	Yes	False tilt	Detailed local geoid highly dependent on density and accuracy of deflection stations. Rapid error accumulation. Bad local datum influence. Currently not expedient at sea. Not compatible.
(2) Astrosatellite	Yes/No	Yes	Possible	Currently poor accuracy at sea as geoid details need highly accurate and dense data distribution. Suitable for evaluation but not absolute calibration of Sat. Alt. "Geoid".
(3) Inertial	No	Not reliable	Not reliable	Very poor accuracy, deficiencies in theory for data deduction. Accurate external geodetic reference required in navigation mode. Not compatible with Sat. Alt. "Geoid".
(4) Gravimetric (a) Stokes'	Yes	No	Possible	Not for ABSOLUTE CALIBRATION but good for shape evaluation. Needs adequate global coverage of data; theory problems in data prediction and reduction. Compatible in shape and orientation only but not in scale.
(b) Vening Meinesz	Yes	Possible dependent on initial point	Possible	More dependent on dense local gravity net and less influenced by distant zone data which are still needed. Problems in prediction and reduction theories. Compatible in shape and orientation but correctness of scale dependent on assumed initial point.
(5) Satellite (a) Geopotential coefficients	Yes	Dependent on method used	General outline	Poor coefficient accuracy, inadequate for geoid details. Not suitable for calibration of Sat. Alt. "Geoid".
(b) Geometric/dynamic	Possible	Yes	Possible	Highly dependent on orbit accuracy and geometry. Could provide in the future compatible detailed geoid profiles.
(6) Combined Satellite/Terrestrial, Astronomic, Geodetic, Gravity	Yes?	Yes?	Yes?	Development of techniques in progress. Theoretically, could provide global geoid using world-wide data coverage. Not suitable for local geoid details as required for satellite altimetry test areas.
(7) Astrogravimetry	Yes	Yes	Yes	Requires ONLY LOCAL GRAVITY data, speedy and economical. BEST suitable for geoid details in Test Areas. COMPATIBLE with expected Sat. Alt. "Geoid" in scale, shape, and orientation.
(8) Satellite Altimetry	Yes	Yes	Yes	Development in progress. If successful, provides the best hope currently for speedy, economical determination of global marine geoid with sufficient accuracy and details to meet oceanographic, [illegible]

Concept of Satellite Altimetry

Figure 1 depicts schematic geocentric relations of the various surfaces associated with satellite altimetry. OB is the satellite orbit defined by the satellite ephemeris. TM is the raw altimeter range which has to be corrected for laboratory instrumental calibration, electromagnetic effects, sea state, atmospheric conditions, tropospheric refraction, and periodic sea surface influences, such as tides, to give TS. S represents the non-periodic "sea level" or mean instantaneous sea level. CT, the geocentric radius of the altimeter, and CE, the geocentric radius of its subsatellite point on the reference ellipsoid, are computed from satellite ephemeris. EG is the absolute geoid undulation or height, which if computed, defines the geoid, while SG is the quasistationary departure of the mean instantaneous sea surface (e.g., due to currents) from the geoid --the "undisturbed" mean sea level. For convenience, the ocean-dependent corrections for M to S are labeled "periodic factors" and for S to G as "non-periodic factors". Generally, SG is near zero except in areas of strong ocean currents where it could be as large as 1 meter.

Simply, the concept of geoid determination from satellite altimetry is to determine EG in the oceans based on the satellite orbit, OB, and the altimeter measurement of range TM which must be correctly processed to become TG. An analytical method for this geodetic processing, the complications involved, and the results thus far obtained from Skylab altimetry data, are discussed in Fubara and Mourad [1974a]. Figure 2,

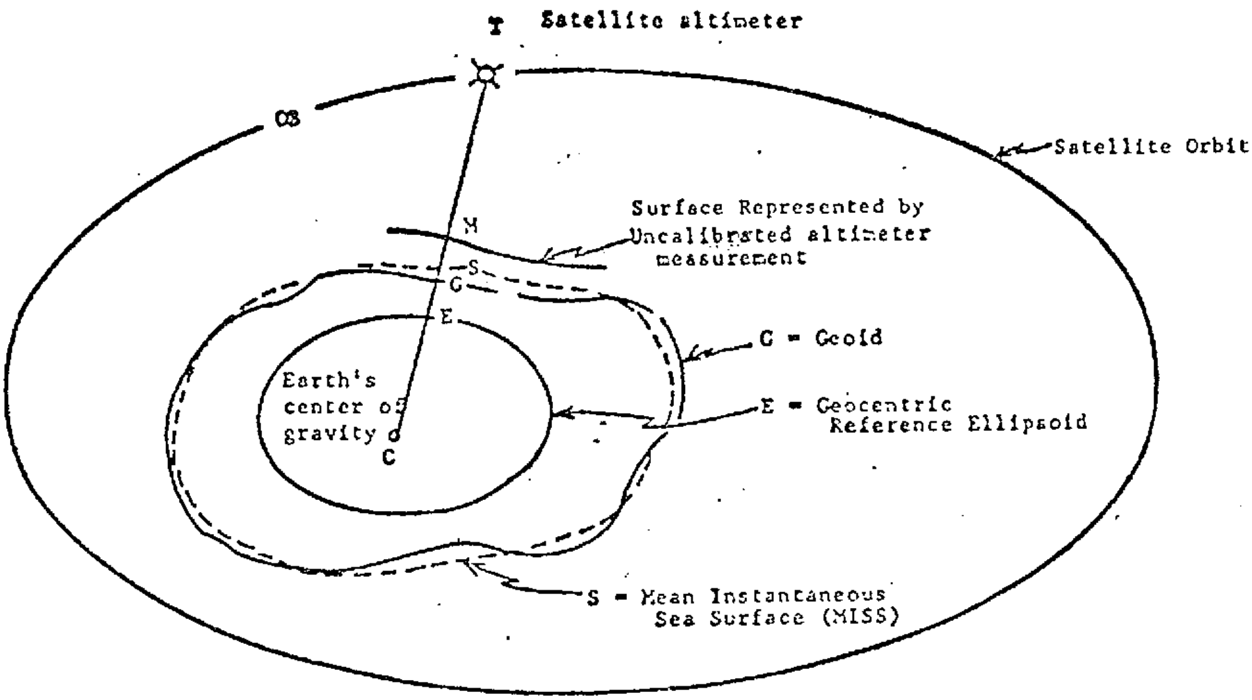

FIGURE 1. GEOCENTRIC RELATIONS OF SURFACES INVOLVED IN SATELLITE ALTIMETRY

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taken from McGoogan et al. [1974], is a sample output from Skylab altimetry. The wavy pattern of Figure 2 is comparable to the "M" of Figure 1. By least squares data processing, a mean curve can be fitted to the wavy "M" raw altimeter data and also corrected to give the geoid G, (see Figure 1). This procedure introduces algebraic correlation and automatically renders the geoid heights deduced from the corrected mean curve G to be highly correlated even if the original altimeter data were uncorrelated.

General Problems and Performance Criteria for Satellite Altimetry Geoid Applications

The main factors are (1) accuracy of orbit determination, (2) the precision and/or accuracy of the altimeter, (3) availability of geodetic ground truth for calibration, validation, and evaluation, and geodetic controls for the scale, orientation, and centering of the resultant geoid, (4) availability and accuracy of correction factors for both the "periodic factors" and "non-periodic factors" which are ocean dependent, and (5) altimeter pointing accuracy, the poor quality of which leads to physical correlation due to pulse to pulse correlation of the altimeter data which are otherwise uncorrelated.

Detailed investigation and discussion of the first three problems are given Fubara and Mourad [1974a and 1974b]. A correct scale is achieved by analytical recovery and application of necessary corrections for the altimeter system biases, systematic radial errors of the orbit ephemeris and the periodic effects of sea surface topography. The success of this operation requires the use of

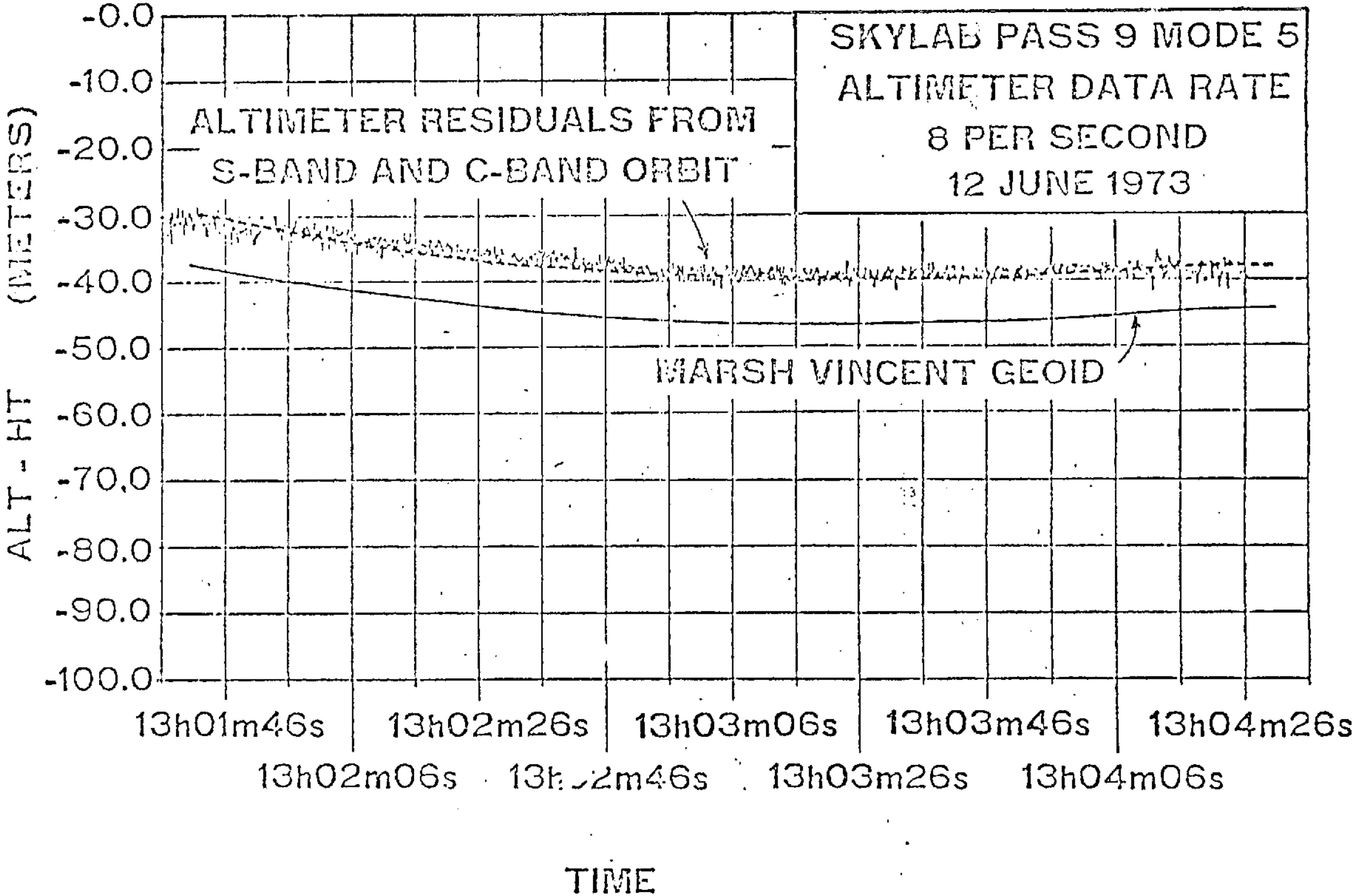
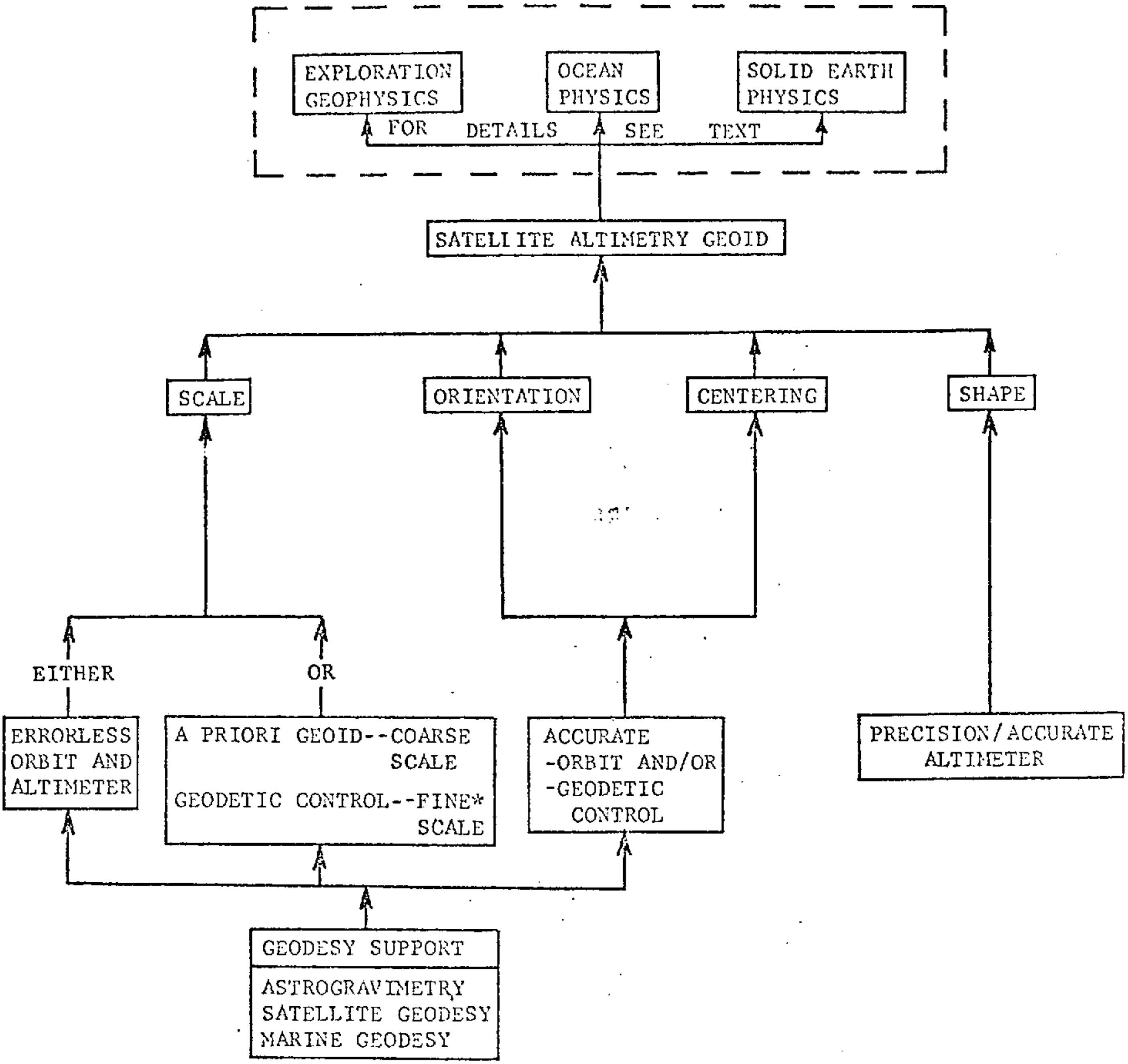


FIGURE 2. SAMPLE DATA FROM SKYLAB ALTIMETER

a priori knowledge of the geoid (best available conventional geoid) for coarse scale definition, and sparsely, but globally, distributed marine geodetic control points for fine scale. Each marine geodetic control point is a station whose three geodetic coordinates are accurately known in a stipulated geodetic datum. The establishment of such points has been demonstrated in Mourad, et al. [1972], Fubara and Mourad [1972b], and Fubara [1973a], for example. Satellite altimetry geoid determination is in effect geometric leveling from space. The marine control points thus serve as 'benchmarks' to permit "closure and adjustment" of the leveling for uniform distribution of random errors and elimination of cumulative errors and prevention of the cantilever phenomenon in open-ended leveling. This requirement can be eliminated only if we had a perfectly errorless orbit ephemeris and a perfect altimeter or a perfect knowledge of the systematic errors or biases of the ephemeris and the altimeter.

A correct shape demands that the altimeter (1) be precise enough to give accurate relative height differences of successive points; and (2) does not drift or the drift characteristics be known more accurately than the error tolerance in the geoid to be computed. Correct orientation and centering are dependent on the satellite ephermeris. However, alternatively or in addition, marine geodetic controls can be used as constraints to achieve proper orientation. Figure 3 is a schematic representation of the performance criteria for successful application of satellite altimetry. Ironically, most of the problems identified (except the altimeter hardware itself) are receiving minimal attention. The need for the geodetic controls and ground truth cannot be over emphasized unless the satellite ephemeris and the altimeter are either errorless or their errors are accurately known and can be corrected for.



* Geoid Accuracy	Correction for Ocean Dependent Phenomena "Periodic Factors"	"Non-periodic Factors"
Over 1 meter	Required	Not Required
Less than 1 meter	Required	Required

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FIGURE 3. PERFORMANCE CRITERIA FOR APPLICATION OF SATELLITE ALTIMETRY

GRAVITY ANOMALIES FROM SATELLITE ALTIMETRY GEOID

This section contains the theoretical background, various approaches to numerical data processing, associated theoretical and practical problems, and discussion of very preliminary results about achievable accuracies in the synthesis of gravity anomalies from satellite altimetry geoid.

Theoretical Fundamentals

From Molodenskii, et al, 1962,

$$\Delta g_p = -G \left[\frac{N_p}{R} + \frac{1}{2\pi} \iint_\sigma \frac{N_i - N_p}{r_{ip}^3} \, d\sigma \right] \qquad (1)$$

σ = a sphere of radius R

r = distance between p and surface element $d\sigma$

$r = 2R \sin \frac{\psi}{2}$

ψ = the spherical distance of p from $d\sigma$

G = normal gravity which from the 1967 Gravity Formula

$\cong 978 \cdot 03185 \, (1 + 0 \cdot 005\ 278\ 895 \sin^2\varphi + 0 \cdot 000\ 023\ 462 \sin^4\varphi)$ gal

(This formula may lead to a maximum error of 0 · 004 mgal)

φ = geodetic latitude

N_p = geoid height at point p

N_i = geoid height for the surface element $d\sigma$

Δg_p = gravity anomaly for area represented by point p.

The N_i and N_p are the only unknown but determinable quantities.

The use of Equation (1) requires, in principle, that (a) geoid height, N, be known worldwide for every surface element, $d\sigma$, (b) all the geoid heights be compatible and based on the same worldwide datum, and (c) the geoid heights in use be based on a "regularized geoid" which is sometimes called the "cogeoid". The regularized geoid is the figure of the geoid of a "regularized earth". Regularization of the earth implies displacement or removal inwards from the earth's surface all masses lying outside the geoid [Molodenskii, et al, 1962]. The practical problems and procedures associated with this regularization are discussed in Heiskanen and Moritz [1967]. The effects of these factors and requirements on the determination of gravity anomalies from geoid heights are discussed later.

The Role of Satellite Altimetry

From satellite altimetry, it is expected that the geoid in the oceans can be determined. The feasibility of this has been demonstrated by Skylab altimetry results as shown in Fubara and Mourad [1974a]. GEOS-C and later SEASAT should advance the determination of the geoid in the oceans (marine geoid) to a precision of 1 meter or better. The marine geoid is about 70% of the global geoid. Therefore, the geodetic processing of satellite altimeter data can provide about 70% of the N_i and N_p required in Equation (1) for computation of gravity anomalies. Conventional methods to achieve determination of the marine geoid are so expensive, time consuming and beset with so many practical and theoretical irregularities and deficiencies [Fubara and Mourad, 1972] that these conventional methods cannot be depended on for achieving the results expected of satellite altimetry. In Fubara and Mourad [1974c] a method has been developed, whereby the marine geoid can be used to rectify the continental "geoids" and hence obtain worldwide data on an informal datum, which can be used to satisfy all the three conditions listed under Equation (1).

Practical Applications of Gravity Anomalies

Knowledge of gravity anomalies is required for various practical and scientific applications, including the following:

(1) Geophysical prospecting for oil, gas, and other minerals

(2) Oceanographic studies for improved understanding and modeling of physical phenomena and dynamics of the oceans

(3) General determination of the earth's gravity field for (a) satellite orbit computation, (b) missile trajectory computations and systems analysis, (c) geodetic datum definition and orientation, network calculations, reductions of geodetic and positional astronomy measurements to an unique equipotential datum, (d) geophysical and geological studies of the physics of the solid earth, (e) improvement of error control in inertial navigation systems.

Applications in (1) above have the most stringent requirements for accuracy and density of data points per chosen unit area, while those in (3) have the least stringent requirements for density, but the most demand for worldwide data. These are further discussed later.

Practical Implementation Approaches

The practical implementation of Equation (1) for computation of gravity anomalies requires that the geoid heights be accurately known worldwide on a uniform global geodetic datum. Satellite altimetry can provide geoid heights in the oceans only. However, on the continents accurate gravity anomalies are known in some places. Consequently, Koch [1970] suggested two possible alternative approaches to the utilization of Equation (1). Gopalapillai [1974] has suggested one more approach that carries out a least squares solution combining available measured gravity data, satellite altimetry data and the use of geopotential coefficients for areas that lack gravity or altimeter data. All three approaches will be briefly discussed as a background to the fourth approach which we advocate should be investigated because it should eliminate the theoretical and practical problems in Koch's two approaches.

Conventionally, the geoid height N_o can be derived from gravity anomalies by using Stokes' formula [Heiskanen and Mortiz, 1967]:

$$N_o = \frac{R}{4\pi G} \iint_\sigma \Delta g \ S(\psi)\, d\bar{\sigma} \tag{2}$$

where

$S(\Psi)$ = Stokes' function and the other parameters except $d\bar{\sigma}$ are as for Equation (1). The $d\bar{\sigma}$ of Equation (2) and $d\sigma$ of Equation (1) are related by

$$d\sigma = R^2 d\bar{\sigma} \ . \tag{3}$$

The proof of Equation (3) to reconcile the differences in the meaning of $d\sigma$ as used in Heiskanen and Mortiz [1967] and Molodenskii, et al. [1962] is derivable from Molodenskii's integral equation

$$\iint_{\sigma} \frac{1}{r} d\sigma = \frac{4\pi R^2}{\rho} \tag{4}$$

where all parameters are as defined under Equation (1). Letting

$$d\sigma = R^2 \sin \Psi \; d\lambda \; d\psi \tag{5}$$

where λ is the geodetic longitude with point p as pole and noting that

$$r = 2R \sin \frac{\psi}{2} \tag{6}$$

then

$$\iint \frac{1}{r} d\sigma = \iint_{0\,0}^{2\pi\,\pi} \frac{R^2 \sin \psi d\lambda d\psi}{2R \sin \frac{\psi}{2}} \quad . \tag{7}$$

After minor trigonometric identity substitutions, Equation (6) becomes

$$\iint \frac{1}{r} d\sigma = R \iint_{0\,0}^{2\pi\,\pi} \cos \frac{\psi}{2} \; d\lambda \;\; 2d\frac{\psi}{2} \;\; = 4 \;\pi\; R \quad . \tag{8}$$

This proves Equation (4), because on the earth's surface, with spherical approximation, $\rho = R$. In Equation (1), we can know N (geoid heights) accurately from satellite altimetry in the oceans but on the continents we do not now have comparable N. In Equation (2), we can have accurate Δg by conventional instrumentation on the continents but not in the oceans without immense cost in time and money.

Koch - Iterative Direct and Inverse Stokes Approach

Based on these facts, one of Koch's approaches is to perform an iterative solution using Equation (1) and the partial required data from satellite altimetry over the oceans, and Equation (2) with the partial required data available on the continents. Basically, Stokes' formula (2) and its inverse (1) are applied in an iterative cycle; that is, approximate values for the gravity anomalies of the oceans are introduced into (2) together with the anomalies measured on the continents in order to get geoid undulations for the continents. These results together with the geoid undulations obtained by satellite altimetry for the oceans are used in (1) to compute gravity anomalies for the oceans. The results together with the observed gravity values are introduced into (2) again and so forth until a sufficient covergence for the results is obtained. There are questions about the convergence of the iterations to an unique solution and the necessary number of iterations.

Koch - Surface Density Layer Approach

Koch's second approach [Koch, 1970] is based on the surface density layer principle as derived by Molodenskii, et al. [1962]. In theory, this approach seeks to avoid inaccuracies caused by various approximations in the use of Equations (1) and (2). It follows the classical method of geodetic boundary value problem by dividing the geopotential, W, of the earth into the potential, U, of a reference ellipsoid and the disturbing potential, T, due to the earth's mass anomalies. Thus,

$$W = U + T \,. \tag{9}$$

The disturbing potential, T, is then represented as the potential of a simple layer of density ϕ distributed over the surface Σ of the earth and is given by

$$T = \iint_{\Sigma} \frac{\phi}{r}\, d\Sigma \tag{10}$$

where r is as previously defined. From Bruns' theorem, [Heiskanen and Moritz, 1967], the geoidal height, N, is

$$N = \frac{T}{G} = \frac{R^2}{G} \iint \frac{\chi}{r}\, d\omega \tag{11}$$

where G is as defined under Equation (1).

As given in Koch [1970], based on Molodenskii, et al, [1962], the gravity anomaly Δg_p at point P is given by

$$\Delta g_p = 2\pi\chi \cos^2 \alpha - \frac{3}{2} R \iint \frac{\chi}{r}\, d\omega - R^2 \iint \frac{H_i - H_p}{r^3}\, \chi d\omega \tag{12}$$

where

χ = ϕ sec α
α = angle between normal to earth's surface and to the reference ellipsoid
H = topographic height above the geoid
$d\omega$ = element of the solid angel subtended by the surface element $d\Sigma$ at the origin.

If the values for the density χ were known all over the earth, (but, in fact, are not known), then the gravity anomaly at each point, P, can be computed from Equation (12). However, that equation holds only for the earth assumed to be spherical. Koch [1969] has determined the corresponding integral for the ellipsoid which is a better approximation of the earth's figure.

Applying Equation (11) in the ocean areas, the geoid heights N obtained from satellite altimetry can be used to compute the surface density values which are unknown in the oceans. On the continents, the gravity anomalies Δg, are determinable and can be applied to Equation (12) to compute values of the surface density. On the basis of Equation (11) and (12) one can in effect combine the accurate continental values of Δg with the accurate oceanic values of N from satellite altimetry in a simultaneous solution by least squares processing and hence obtain gravity anomalies in the oceans.

To make this theory workable in practice is a monumental task that will require a major research effort, as can be seen from pages 118-124 of Molodenskii, et al, [1962] which discussed "solution of the fundamental equation" in the surface density layer approach.

Gopalapillai Combination Approach

This approach suggests how to (a) avoid Koch's iterative procedure, (b) dispense with the difficulties in the surface density layer approach, and yet (c) utilize simultaneously all currently available gravity data on land and at sea, together with satellite altimetry data and geopotential coefficients for areas of the world that have neither gravity nor altimetry data.

The anomaly, Δg_p, can be considered to be composed of three components: Δg_1, Δg_2, and Δg_3 such that:

$$\Delta g_p = \Delta g_1 + \Delta g_2 + \Delta g_3 \qquad (13)$$

where:

$$\Delta g_1 = G\sum_{n=2}^{N_{max}} (n - 1) \sum_{m=o}^{n} \left(\bar{C}_{nm}\cos m\lambda + \bar{S}_{nm}\sin m\lambda\right) \bar{P}_{nm}(\sin\varphi) \tag{14}$$

and $\bar{C}_{nm}$, $\bar{S}_{nm}$ - Fully normalized spherical harmonic potential coefficients referred to the same reference field as that to which the undulations in Equation (1) refer.

$\bar{P}_{nm}(\sin\varphi)$ - Fully normalized associated Legendre functions.

(φ,λ) - Geocentric latitude, longitude of P.

N_{max} - Maximum degree to which the potential coefficient set is used.

Then:

$$\Delta g_2 = - \frac{G(N_p - N_{ps})}{R} - \frac{G}{16\pi R^3}\left[\iint_{\sigma_c} \frac{(N - N_s)}{\sin^3\psi/2} d\sigma - \iint_{\sigma} \frac{N_p - N_{ps}}{\sin^3\psi/2} d\sigma\right] . \tag{15}$$

where

$$N_{ps} = R\sum_{n=2}^{N_{max}} \sum_{m=0}^{n} \left(\bar{C}_{nm}\cos m\lambda + \bar{S}_{nm}\sin m\lambda\right)\bar{P}_{nm}(\sin\varphi) \tag{16}$$

and

$$N_s = R\sum_{n=2}^{N_{max}} \sum_{m=0}^{n} \left(\bar{C}_{nm}\cos m\lambda' + \bar{S}_{nm}\sin m\lambda'\right)\bar{P}_{nm}(\sin\varphi') \tag{17}$$

with (φ', λ'), the geocentric coordinates of the center of the block whose undulation is N and σ_c is the area of a spherical cap of radius ψ_o around the point of computation.

$$\Delta g_3 = - \frac{G}{16\pi R^3} \iint_{\sigma-\sigma_c} \frac{N - N_s}{\sin^3\psi/2} d\sigma \tag{18}$$

where $\sigma - \sigma_c$ is the area of the earth's surface outside the cap (remote zones).

The magnitude of Δg_3 depends on the size of the cap and on the maximum degree, N_{max}, of the potential coefficient set used. Δg_3, if neglected, would be the error in using approximate values as obtained from the set of potential coefficients, for N in the remote zones. This error in remote zone contribution can be made small by choosing ψ_o and N_{max} large. On the other hand, it must be remembered that as N_{max} increases the accuracy with which the potential coefficients are known decreases, and the error in Δg_p due to the approximation of the undulations in the remote zone thus increases with increase in N_{max}. Also, with the increase in ψ_o, the computational effort is unduly increased without corresponding improvement in the accuracy of Δg_p. Therefore, it is necessary to choose a cap size such that the neglected contribution of the remote zone is well below the accuracy desired in Δg_p without unduly increasing the computation effort.

This approach appears to be more satisfactory for practical implementation than either of Koch's approaches. It should satisfy application requirements for "solid earth physics" as previously defined. It is doubtful that it can meet the requirements of "ocean physics" or "exploration geophysics" applications. Extreme care is necessary to ensure that the various data being combined are "physically" compatible. The method is highly vulnerable to errors in the variance-covariance functions that must be used for weighting criteria.

Fubara - Non-iterative Inverse Stokes Approach

Each of the above appraocies has sought an efficient way to utilize hybrid data. Every approach must address this same problem since satellite altimetry data over the continents are not suitable in practice for determination of the "continental" geoid while the gravity data on the continents are highly accurate and must be utilized. The non-iterative approach discussed in Fubara and Mourad [1974c] is designed not only to use the data implied in the previous three methods, but also any other gravity field descriptive data including even astrogeodetic geoids. The fundamental basis is the use of Equation (1) which is the inverse Stokes' formula. Similar to the derivations for the "Template method" for the practical use of the direct Stokes' formula in physical geodesy, it can be shown that Equation (1) can be rewritten [Fubara and Mourad, 1974b] as

$$\Delta g_p = \frac{-G}{R}\left[N_p + \frac{1}{16\pi R^2}\sum_i \frac{\Delta N_i A_i}{\sin^3 \frac{\psi}{2}}\right] \tag{19}$$

by replacing the integral with a summation where $\Delta N_i = N_i - N_p$ is the mean value for the surface area A_i. Before the use of Equation (19), the geoid heights in the oceans (marine geoid) from satellite altimetry are used for datum establishment and geoid "rectification" of the "continental geoids" [Fubara and Mourad, 1974]. The reason for this is that, due to various theoretical and practical problems discussed in Fubara and Mourad [1972], there are as many "continental geoids" as the number of authors who determined them. These "geoids" all differ from one another in scale, shape, orientation and absolute centering.

They are not directly compatible and are not as accurate as the geoid can be from satellite altimetry. Furthermore, the satellite altimetry geoid is regularized because the only mass above the oceans is the atmosphere whose effect can be neglected. By this process of geoid rectification we obtain worldwide geoid data which satisfy conditions (a), (b), and (c) described under Equation (1). Thus, all the data and parameters required for the practical application of Equation (19) for computation of gravity anomalies become available.

Problems of Practical Implementation Approaches

Each of the above four approaches has many unanswered questions. The first has not been applied in practice. The second has not been used directly for gravity anomaly recovery; but the concept has been applied in various ways with some measure of success in gravity field representation in the works of Koch, Morrison, and Witte of NOS/NOAA. Gopalapillai has conducted limited tests of his method (private communication). Fubara's approach has had very limited testing and appears to be efficient.

The main topics that give rise to problems in these approaches include:

(1) Regularization of the earth, where applicable, imposes (a) reduction requirements not easily achievable for measured terrestrial gravity anomalies used as inputs in these methods and (b) distortion of the gravity anomalies computed as outputs from the use of these approaches. Such gravity anomalies may significantly differ from the true values of the actual earth. This is of most important concern in the use of gravity

anomalies for exploration geophysics.

(2) Data processing and actual numerical solution of the fundamental equation(s) in each approach, convergency and uniqueness of solution.

(3) The strong correlations (both physical and algebraic) among parameters and data impose stringent requirements for proper knowledge and use of correct variance-covariance functions that need to be established by theoretical research.

(4) The ease of subjecting the fundamental equation(s) of each approach to simulation studies and error propagation analyses.

(5) Data requirements: (a) accuracy of input, (b) local or worldwide availability and distribution, and (c) density of distribution. The density of the distribution of input data is most critical in computing gravity anomalies for geophysical prospecting or mineral exploration. For example, this means that if the oil companies need gravity anomalies for each n X n sq km area, then the altimeter data coverage should be for each surface area not larger than n X n sq km. Currently, it is desirable that $1 \text{ km} \leq n \leq 8 \text{ km}$, for mineral exploration needs.

(6) Theoretical approximations and physical assumptions in derivations involved in each approach.

(7) Accuracy of output (the gravity anomalies) which is dependent on the above factors and the relevance of such attainable accuracy in meeting the objectives of

the practical applications for which the gravity anomalies are desired.

(8) The size of geoidal variations created by various geological formations of interest in geophysical prospecting is undetermined, a preliminary look indicates that these might be very small and, hence, masked in noise level of satellite altimetry.

Ideally, the next step is to investigate how each of the above sources of problems applies to the various approaches described, and so determine what type of accuracy can be achieved in computing gravity anomalies from satellite altimetry and which method is best in practice.

Preliminary Results of Quick-Look Simulation Study

A very limited investigation based on simulated data has been conducted, using the Fubara-noniterative approach. First it was necessary to verify that Equation (19) can be applied in practice. Then, the accuracy with which desired gravity anomalies could be recovered was investigated. This section includes discussions of the corresponding very cursory theoretical error analyses in terms of both statistical propagation and physical propagation. Also, a very preliminary investigation of the effect of integrating Equation (1) up to a given limit of ψ, instead of globally, was made. In geodesy, this is called the influence of the neglected zone.

Validation of Fubara's Approach

There is a basic relationship between geoid heights, N, the gravity anomalies, Δg, and the potential coefficients of the earth's gravity field as given by Equations (20) and (21).

$$N = R\sum_{n=2}^{N_{max}} \sum_{m=o}^{n} \left(\overline{C}_{nm}\cos m\lambda + \overline{S}_{nm}\sin m\lambda\right) \overline{P}_{nm}(\sin\varphi) \tag{20}$$

$$\Delta g = G\sum_{n=o}^{N_{max}} (n - 1)\sum_{m=o}^{n} \left(\overline{C}_{nm}\cos m\lambda + \overline{S}_{nm} \sin m\lambda\right) \overline{P}_{nm}(\sin\varphi) \tag{21}$$

where:

N_{max}	is the highest degree of coefficients considered
$\overline{C}_{nm}$, $\overline{S}_{nm}$	are fully normalized potential coefficients referenced to a given ellipsoid
$\overline{P}_{nm}$	are the fully normalized associated Legendre functions
λ	is the geodetic longitude of computation point
φ	is the geodetic latitude of computation point

To obtain the potential coefficients referred to in Equations (20) and (21), the actual earth gravity field spherical potential coefficients C_{mn}, S_{mn} are modified by Equation (22)

$$\begin{aligned} \overline{C}_{no} &= C_{no} - J_n(2n + 1)^{-1/2} \\ \overline{C}_{nm} &= C_{nm} \qquad (m \neq o) \\ \overline{S}_{nm} &= S_{nm} \end{aligned} \tag{22}$$

where the J_n are geodetic physical constants of the earth's ellipsoid in use.

From Equations (19), (20), and (21) it is known that

$$\Delta\bar{g} = F_1(N) \tag{23}$$

$$N = f_2(\bar{C}_{nm}, \bar{S}_{nm}) \tag{24}$$

$$\Delta g = f_3(\bar{C}_{nm}, \bar{S}_{nm}) \tag{25}$$

In theory, therefore, from a given set of $\bar{C}_{nm}$ and $\bar{S}_{nm}$, if the N from Equation (24) is used, in Equation (23), then Δg from Equation (25) minus $\Delta\bar{g}$ from Equation (23) should be zero. There are, in practice, many reasons to obtain $\Delta g - \Delta\bar{g} \neq 0$, exactly. However, in the absence of gross errors in the equations and their practical computation, $\Delta g - \Delta\bar{g}$ should be small. In a sample computation made for mean anomalies Δg_p for a $4^\circ \times 4^\circ$ integration block size (i.e., $A_i = 4^\circ \times 4^\circ$ in Equation (19)), $\Delta g_p = 9.057$ mgal and $\Delta\bar{g}_p = 8.398$ mgal were obtained. The error of recovery is -0.659 mgal. This is a validation of the practical utility of Equation (19). For the above computation, the distance of integration from point P was $\psi = 56^\circ$. Other preliminary calculations showed, as expacted, that as $\psi \rightarrow 0^\circ$, $\Delta g - \Delta\bar{g} \rightarrow \infty$. It is necessary to investigate, in detail, the dependency of $(\Delta g - \Delta\bar{g})$ on the size of ψ. For practical applications, exploration geophysics generally requires block sizes, A, less than 10 km x 10 km. An investigation into required block sizes to satisfy the three major categories for application of graviety anomalies is necessary.

Error Analyses

The discussions here are based on very limited numerical computations and an arbitrary assumption of unit variance in the estimates of the geoidal heights. The preliminary results should not be quoted out of context. However, there is no doubt, that the preliminary error estimates and conclusions in Koch [1970] about achievable accuracy in the use of Equation (1) for computing gravity anomalies are grossly in error. Koch's error stems from his assumption in a rough calculation, that the error arising from the integral on the right side of Equation (1) can be neglected. In fact, errors accumulated by the integral terms are greater by about 4 to 1 than the term Koch had considered to be more dominant. Koch's [1970] conclusions, that a 10 meter geoid error produces a 1.5 mgal error in the derived gravity anomaly or that ± 5 meter accuracy altimeter will produce errors of about ± 1 mgal, appear to be

The conclusion here is based on preliminary calculations of statistical error propagation using Equation (1) in its entirety as modified and represented by Equation (19). Assuming no correlation between the N_i for each block, preliminary calculations show that geoid heights of ± 1 meter (one sigma) produce errors in estimated gravity anomalies of about ± 10 to 15 mgals in $1^\circ \times 1^\circ$ blocks. This has been shown elsewhere to be invalid in practice. Therefore, in practical applications, determination of the correlation is an important requirement for the reliability of both the computation and error estimates. Detailed work needs to be done to establish (1) more reliable accuracy information and (2) the accuracy dependency on block sizes used. A preliminary look at these questions is presented in Appendix A.

For exploration geophysics, accurate knowledge of the absolute values of Δg is less important than that of the local variations in Δg. The issue, therefore, is whether local relative differences, $\Delta g_{pq} = \Delta g_p - \Delta g_q$, between two adjacent points, p and q, can be determined such that the error of Δg_{pq} is less than the error of Δg_p or Δg_q.

Calculations indicate that for two neighboring points, p and q, the variances σ_p^2 and σ_q^2 of Δg_p and Δg_q, assuming a uniform grid spacing in the data, are approximately equal. Applying the propogation of variance formula, the variance σ_{p-q}^2 of $\Delta g_p - \Delta g_q$ is given by

$$\sigma_{p-q}^2 = \sigma_p^2 + \sigma_q^2 + 2\varepsilon\sigma_p\sigma_q \tag{26}$$

where

$$\rho = \sigma_{pq}/\sigma_p\sigma_q \quad \text{and } -1 \leq \rho \leq 1$$

ρ is the correlation efficient and σ_{pq} is the covariance term. (Note the distinction between σ_{p-q} and σ_{pq}). Since it was found that $\sigma_p \cong \sigma_q$, Equation (26) can be reduced by letting $\sigma_p = \sigma_q = \sigma$ to

$$\sigma_{p-q}^2 = 2\sigma^2 + 2\rho\sigma^2 \tag{27}$$

hence, $$o \leq \sigma_{p-q}^2 \leq 4\sigma^2 \quad . \tag{28}$$

It follows that the magnitude and sign of the correlation between the geoid heights, N_p and N_q, for p and q respectively, is of utmost importance. Satisfactory investigation to determine the correlation coefficient cannot be over emphasized. Earlier, we have shown that N_p and N_q are correlated by the algebraic correlation imposed by the least squares data processing to derive N_p and N_q. Furthermore, if the altimeter nadir pointing is significantly in error, the original altimeter data become correlated even before they are processed to derive geoid heights. This physical data correlation, which should be avoided, arises from radar pulse-to-pulse correlation theory.

There are other physical relations between Δg_p, N, ξ_p, and η_p that can be used for error propagation analyses. ξ_p is the meridian component and η_p is the prime vertical component of the deflection of the vertical at point p. Furthermore, in any given azimuth, α, the total deflection of the vertical, θ, in that azimuth is

$$\theta = \xi\cos\alpha + \eta\sin\alpha \quad . \tag{29}$$

From geodesy

$$N_q - N_p = \int_p^q \theta d L \tag{30}$$

where l = length pq. It can be shown that for suitable choice of L,

$$N_q - N_p = 1/2 \ (\theta''_p + \theta''_q) \, L \sin 1'' \quad . \tag{31}$$

The sign, ", in Equation (31) is for arc seconds. As shown by derivation in Molodenskii, et al, [1962] and Heiskanen and Moritz [1967]

$$\Delta g \Leftrightarrow f_1(\theta) \Leftrightarrow f_2(N) \quad . \tag{32}$$

The summation term of Equation (19) can be rewritten as

$$\Sigma \cdot \frac{N_i - N_p}{r_{ip}} \cdot \frac{A_i}{r_{ip}^2} \tag{33}$$

This is approximately

$$\sum \theta_{pi} \cdot \frac{A}{r_{ip}^2}$$

These functional relationships should be used for supporting error analyses in the synthesis of Δg from N. Again, preliminary error propagation based on all these functional relationships indicate that Koch's [1970] estimate (1.5 mgal for 10 meter geoid error) is in error and should not be quoted. From this study, preliminary estimates are shown to be on the order of 10 mgal for 1 meter geoid error, using $1^{\circ} \times 1^{\circ}$ block sizes.

CONCLUSIONS

(1) For the benefits of all the practical applications given earlier, the SEASAT program is required.

(2) For "solid earth physics" (see earlier definition) a 1 meter geoid accuracy will give better, speedier, and more economical results than can be achieved by any currently known methods. The objectives of "ocean physics" and "exploration geophysics" application appear to require a better than 10 cm in geoid accuracy. To achieve this level of accuracy in geoid determination is currently difficult but may not be impossible in the future. Besides orbit accuracy, the major drawback in obtaining a 10 cm geoid from satellite altimetry are the corrections for (a) the "periodic" and (b) "non-periodic" ocean dependent factors discussed earlier. Ironically, factor (b) is one of the main parameters of interest to "ocean physics" applications. A 1 meter geoid, however, does not need correction factor (b).

(3) The need for geodetic groundtruth for calibration and evaluation, and geodetic controls for true scale and orientation control cannot be over-emphasized. This need is currently not receiving

APPENDIX B1

A PRELIMINARY ERROR ANALYSIS OF GRAVITY ANOMALY DETERMINATIONS BASED ON STOKES INVERSE FORMULA

The methods for determining gravity anomalies with the aid of satellite altimetry described in this can be divided into two groups, "Pure-hybrid" and "Non-hybrid". The pure-hybrid methods are based upon using satellite altimetry data in direct combination solution with other conventional geodetic data such as geopotential coefficients and measured gravity anomalies in their original state for the synthesis of gravity anomalies. In the non-hybrid method, the other conventional geodetic data are first transformed into geoidal data compatiable with satellite altimetry data before they are used in computing the gravity anomaly. For this method, Δg_p, at a point, P, is based upon Equation (A-1),

$$\Delta g_p = - \frac{GN_p}{R} - \frac{G}{2\pi} \iint_\sigma \frac{N_i - N_p}{r_{ip}^3} d\sigma(i) \qquad \text{(A-1)}$$

where:

N_i = height of geoid above reference ellipsoid at point i

r_{ip} = distance between point i and p

G = mean gravity over Earth's surface

R = mean radius of Earth

σ = surface of the Earth .

As shown earlier Equation (A-1) is the inverse of Stokes formula. The application of Equation (A-1) in practice requires that the integral be approximated by a finite sum and, in addition, the geoid heights must be determined from satellite altimetry and/or other sources. Both of these facts are potentially the major sources of error in computing the gravity anomalies. Accordingly, to assess the practical significance of this approach, several questions must be answered. Among these are:

- How accurately can a finite sum represent the integral?
- What is the magnitude of the error that is introduced if the integral is evaluated over part of the surface only?
- How does the truncation error depend on the size of the neglected zone?
- What will be the error in Δg_p due to errors in N_p and the other N_i?
- For neighboring points, p and q, what will be the error in the difference, $\Delta g_p - \Delta g_q$?

The analysis of the non-hybrid method is done by examining the finite sum approximation to the integral as in Equation (A-2).

$$\Delta g_p = - \frac{GN_p}{R} - \frac{G}{2\pi} \sum_{i \neq p} \frac{N_i - N_p}{r_{ip}^3} \Delta A_i \qquad \text{(A-2)}$$

where N_i is the mean geoid height for the surface area ΔA_i of the Earth. In this analysis it is assumed that the surface of the Earth is divided into a grid with block sizes of equal latitude and longitude differences. The mean geoid height is taken to be at the center of each block.

The analysis of how accurate a finite sum will represent the integral was done as follows. A set of spherical harmonic coefficients, C_{mn} and S_{mn}, were taken to be an exact representation of a potential field. From these, both the gravity anamolies and the geoid undulations could be determined. These values are then assumed to be exact. The right hand side of Equation (A-2) is then evaluated to determine the error in the finite sum approximation. By varying the maximum value of r_{ip} used, the necessity of integrating over the entire surface or the influence of the neglected zone can be examined.

In this analysis, a finite summation area consisting of 29 x 29 blocks was used to represent the integral. This grid was centered at 30° latitude and -40° longitude. Four different r_{ip} maxima were considered, 7°, 14°, 28°, and 56°. The gravity anomaly was then computed for the center block. For maximum $r_{ip} = 56^\circ$ and a block size of $\Delta A = 4^\circ \times 4^\circ$ at latitude 30° N and longitude 40° W, the following results were obtained:

Δg from Equation (A-2) = 8.3878 mgal

Δg from Geopotential Coefficients = 9.0571 mgal

To examine the effects of errors in the geoid height determinations on gravity anomaly calculations, Equation (A-2) is rearranged to give Equation (A-3)

$$\Delta g_p = C_p N_p + \sum_{i \neq p} C_{ip} N_i \tag{A-3}$$

where

$$C_p = -\frac{G}{R} + \frac{G}{2\pi} \sum_{i \neq p} \frac{\Delta A_i}{r_{ip}^3}$$

and

$$C_{ip} = -\frac{G \Delta A_i}{2\pi r_{ip}^3}$$

The effect of errors in geoid heights on (1) mean gravity anomalies for an individual block and (2) differences between mean gravity anomalies for neighboring blocks is determined by collecting the coefficients of each N and examining various assumptions about the size of the errors in N and correlations between errors in different N. Specifically, collecting coefficients of N_p and N_i used in the determination of the gravity anomaly at point P yields

$$\Delta g_p = -\frac{GN_p}{R} - \frac{G}{2\pi}\iint_\sigma \frac{N_i - N_p}{r_{ip}^3}\, d\sigma$$

$$= -\frac{GN_p}{R} - \frac{G}{2\pi}\sum_{i \neq p} \frac{N_i - N_p}{r_{ip}^3}\, \Delta A_i$$

$$= \left\{-\frac{G}{R} + \frac{G}{2\pi}\sum_{i \neq p}\frac{\Delta A_i}{r_{ip}^3}\right\} N_p - \sum_{i \neq p}\left\{\frac{G\Delta A_i}{2\pi r_{ip}^3}\right\} N_i \qquad \text{(A-4)}$$

Simularly, collecting coefficients of N_p, N_q, and N_i used in the determination of the difference in gravity anomalies at two points P and Q yields

$$\Delta g_p - \Delta g_q = -\frac{GN_p}{R} - \frac{G}{2\pi}\sum_{i \neq p}\frac{N_i - N_p\,\Delta A_i}{r_{ip}^3} + \frac{GN_q}{R} + \frac{G}{2\pi}\sum_{i \neq q}\frac{N_i - N_q\,\Delta A_i}{r_{iq}^3}$$

$$= \left\{-\frac{G}{R} + \frac{G}{2\pi}\sum_{i \neq p}\frac{\Delta A_i}{r_{ip}^3} + \frac{G\Delta A_q}{2\pi r_{pq}^3}\right\} N_p \qquad \text{(A-5)}$$

$$+ \left\{+\frac{G}{R} - \frac{G}{2\pi}\sum_{i \neq q}\frac{\Delta A_i}{r_{iq}^3} - \frac{G\Delta A_p}{2\pi r_{pq}^3}\right\} N_Q$$

$$- \frac{G}{2\pi}\sum_{\substack{i \neq p \\ i \neq q}}\left\{\frac{1}{r_{ip}^3} - \frac{1}{r_{iq}^3}\right\}\Delta A_i N_i$$

From equation (A-5), it follows that the gradient in gravity anomalies between two points, P and Q, $\Delta g_p - \Delta g_q$ can be expressed in terms of the geoid heights at P and Q and the set of neighboring points, i, represented by any specified block sizes. This change is given in equation (A-6) by rewriting equation (A-5) as follows.

$$\Delta g_p - \Delta g_q = D_p N_p - D_q N_q + \sum_{i \neq p,q} D_{ipq} N_i \qquad \text{(A-6)}$$

where

$$D_p = -\frac{G}{R} + \frac{G \Delta A_q}{2\pi r_{pg}^3} + \frac{G}{2\pi} \sum_{i \neq p} \frac{\Delta A_i}{r_{ip}^3}$$

$$D_q = -\frac{G}{R} + \frac{G \Delta A_p}{2\pi r_{pq}^3} + \frac{G}{2\pi} \sum_{i \neq q} \frac{\Delta A_i}{r_{iq}^3}$$

$$D_{ipq} = -\frac{G \Delta A_i}{2\pi} \left(r_{ip}^{-3} - r_{iq}^{-3} \right) .$$

Using $1^\circ \times 1^\circ$ blocks and evaluating the sums over the entire surface of the Earth gives the results in Table A-1.

TABLE A-1. COEFFICIENTS FOR GRAVITY ANOMALY SENSITIVITY TO ERRORS IN GEOID HEIGHTS OF DIFFERENT BLOCKS

Term(s)	Value (mgal/M) for $\varphi_p = 30^o$, $\varphi_q = 29^o$ $\lambda_p = \lambda_q = 0$
C_p	13.890
$\left(\sum_{i \neq p} C_{ip}^2\right)^{1/2}$	3.362
D_p	14.614
D_q	14.709
$\left(\sum_{i \neq p,q} D_{ipq}^2\right)^{1/2}$	3.153

It is necessary to reconcile (a) the basis for these values, (b) Equation A-3 and (c) the attached yellow sheet

From Table A-1 it is clear that the error in geoid height at the point, P, is the critical term in the accuracy of the determination of Δg_p. In estimating the error in the difference of gravity anomalies at neighboring blocks, the correlation between the errors in geoid undulations becomes critical. The actual correlation depends on how the geoid undulations are determined from the altimetry measurements (and other data).

To examine the sensitivity of C_p to block size, the summation is evaluated by the integral which it approximates over the earth's surface minus the spherical cap or block around the computation point, as shown in Equation A-7.

$$\sum_{i \neq p} \frac{\Delta A_i}{r_{ip}^3} = T \approx \iint_{\sigma - \Delta A_p} \frac{dr}{r_{ip}^3} \qquad \text{(A-7)}$$

If the spherical cap around the point P is approximated by a disk or radius then the integral can be evaluated in closed form, as given by Equations (A-8) - (A-10).

$$T = \int_{\epsilon}^{\pi}\int_{0}^{2\pi} \frac{R^2 \sin \psi d\theta d\psi}{8R^3 \sin^3 \frac{\psi}{2}} \tag{A-8}$$

$$= \frac{\pi}{4r}\int_{\epsilon}^{\pi} \frac{\sin \psi d\psi}{\sin^3 \frac{\psi}{2}} = \frac{\pi}{\sqrt{2}R}\int_{\epsilon}^{\pi} \frac{\sin \psi d\psi}{(1 - \cos \psi)^{3/2}} \tag{A-9}$$

$$= -\frac{\sqrt{2}\pi}{R}\left\{\frac{1}{\sqrt{2}} - \frac{1}{\sqrt{1- \cos \epsilon}}\right\} \tag{A-10}$$

For small ϵ, $1-\cos \epsilon \doteq \epsilon^2/2$, thus we have the sensitivity give in Equation (A-11), base Equations (A-10) and (A-4).

$$\Delta g_p = \left\{ - \frac{3G}{2R} + \frac{G}{R\epsilon}\right\} N_p + \ldots$$

To compare with the result in Table A-1, the disk was taken to have the same area, thus $\pi\epsilon^2 = (1^o)^2 \cos 30$; i.e., $\epsilon = .525^o$. This yields

$$\Delta g_p = 16.53\ N_p + \ldots .$$

It should be noted the variance associated with N_p will depend on the block size for which N_p represents the average geoidal height.

The analysis becomes very critically dependent on the correlation between the N_i and N_p. It is seen from Equation (A-5) that if the errors in the geoid heights at points P and Q are highly correlated; then, the major sources of error will cancel and the error in the difference will be significantly smaller. This argument can be extended to the neighboring N_i to show that errors in these terms will tend to cancel errors in N_p.

There are several questions which remain to be answered. These include the following:

(1) What is the correlation between various N_i?

(2) How will partial correlation reduce the sensitivity to the geoid measurements?

(3) What is the behavior of the terms D_{ipq} when the grid size is changed:

Answers to these questions require a substantially more intensive analysis than was possible in this preliminary investigation.

satisfactory attention. Yet, it holds the key to the success of any satellite altimetry program.

(4) The Gopalapillai and Fubara approaches are workable in practice.

RECOMMENDATIONS

(1) An intensive investigation using the Gopalapillai and Fubara approaches to address the problem topics in the previous section (problems of practical implementation approaches) should be conducted.

(2) A test site or geodetic test range area should be established by marine geodetic techniques involving both satellite geodesy and astrogravimetry for calibration, validation and evaluation of satellite altimetry program.

(3) It will be necessary to establish a number of geodetic control points in all oceans in support of fine scale determination and error control in satellite altimetry applications.

(4) The size of geoidal variation which can be caused by various geological formations of interest in geophysical prospecting needs complete investigation.

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APPENDIX B2

GRAVIMETRY REQUIREMENTS FOR MINERAL EXPLORATION

In the currently proposed SEASAT configuration, it is expected that a direct measurement of the marine geoid will be made. This will be done by determining the distance from the satellite to the average height of the sea surface at the subsatellite point for a arbitrarily large number of satellite positions. To the extent that the position of the satellite is known via its ephemeris, it will be possible to determine the position of the subsatellite surface point with respect to the center of the earth, and thus, determine the geoid with respect to any chosen reference ellipsoid.

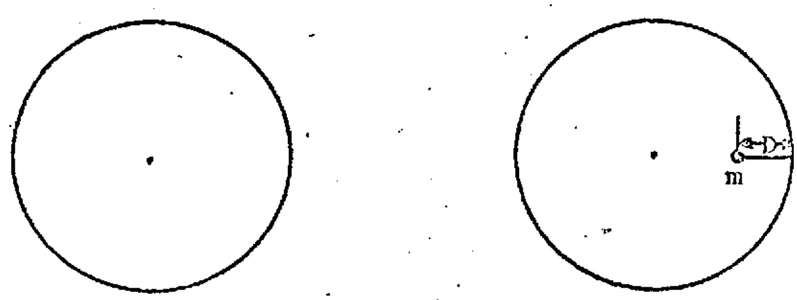
One of the applications of the geoid thus determined is its potential for detecting mass anomalies beneath the ocean surface which would be promising sites to search for oil and mineral concentrations. If SEASAT is to be successful in this application, it must provide data which are suitable in kind, and in accuracy to permit this detection.

The first question to be answered is that of the data type and accuracy requirements engendered by this application of satellite altimetry. The purpose of this paper is to give a preliminary estimate of these requirements.

A Mathematical Model

It seems axiomatic that, at a minimum, the accuracy of determination of the geoid should be capable of distinguishing the geoids produced by the two hypotheses (a) the searched-for mineral deposit is present, and (b) the deposit is not present. Therefore, as a first step, one must attempt to answer the question, what happens to the geoid when a sizable mineral deposit is "added" to a homogeneous earth?

For this purpose, it seems to be adequate to compare two geopotential surfaces: (a) that of a homogeneous, uniform spherical earth, and (b) the same, as in (a), except that a mass concentration of magnitude m has been added at a distance D beneath the surface. This is clearly an idealization, but it does contain the essentials of the problem.



Case (a) Uniform Spherical Earth

Case (b) Spherical Earth with added mass

FIGURE B-1. SCHEMATIC REPRESENTATION OF TWO EARTH MASS DISTRIBUTIONS DIFFERING ONLY IN AN ADDED POINT MASS IN CASE b.

The potential is given by,

$$W(x,y,z) = U(s,y,z) + T(x,y,z) \qquad \text{(B-1)}$$

where U is the potential associated with the uniform earth and T is the potential associated with the added mass. The perturbed geopotential is given by,

$$W(x,y,z) = W_o \qquad \text{(B-2)}$$

and the reference uniform geopotential is given by

$$U(x,y,z) = W_o \quad . \qquad \text{(B-3)}$$

The (vertical) distance, N, between the two geopotential surfaces is given by the Bruns formula as*

$$N = T/\gamma \qquad \text{(B-4)}$$

where γ is the gravitational force (per unit mass) at the reference geoid.

To determine the separation of the two geopotential surfaces, which is akin to change in geoid height, then, it is necessary to evaluate T, the potential of the added mass, over the surface of the reference uniform geopotentials. Referring to Figure B-2, this means determining the value of T at various points P on the reference geoid.

From the standpoint of the potentials involved, it is possible to replace the entire earth by a point mass, M, at the center. It will simplify the computation to evaluate T at points P' rather than points P. For the small distances over the earth's surface, the two points will be very close together, and the value of T will be about the same at both.

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* See, e.g., Weikko A. Heiskanen and Helmut Moritz, Physical Geodesy, San Francisco, W. H. Freeman and Company, 1967, p 85.

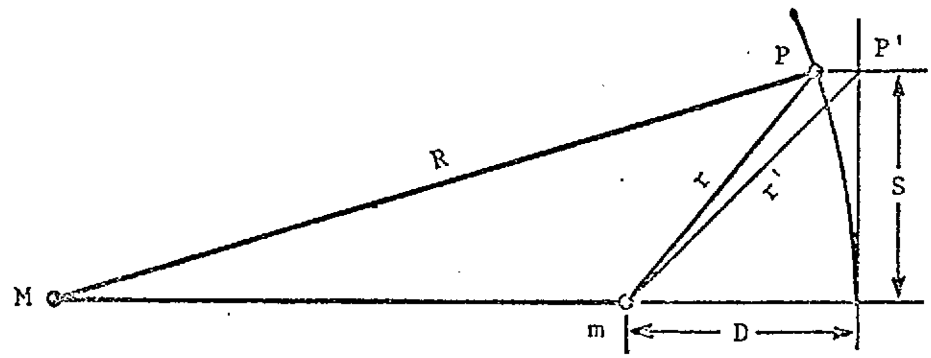

FIGURE B-2. SCHEMATIC DIAGRAM ILLUSTRATING THE DIFFERENCE OF THE TWO GEOPOTENTIAL SURFACES

The potential function at P' is given by

$$T' = \frac{km}{r'} = \frac{km}{\sqrt{S^2 + D^2}} \quad . \tag{B-5}$$

Since the gravity force at the reference geopotential surface is $\gamma = kM/R^2$, it follows that the displacement of the geoid is

$$N(S) = \frac{mR^2}{M\sqrt{S^2 + D^2}} \quad . \tag{B-6}$$

To determine the general shape of the geoid deflection produced by the added point mass M, it is now necessary to describe the characteristics of this function N(S). Clearly, when S = 0 (the point directly over the added mass) N will have its maximum value. This value is

$$N(0) = \frac{mR^2}{MD} \tag{B-7}$$

It can easily be shown that the deviation will be half this large when $S = \sqrt{3}\,D$. Thus, the pattern of deviation in the geoid which will be produced by the added mass is as indicated in Figure B-3.

It is a symmetrical hill whose diameter is of the order of magnitude of the distance of the point mass below the surface. The height of the hill is proportional to the magnitude of the mass, and inversely proportional to its depth below the surface.

Turning now to the gravity anomaly associated with this added mass, it is given by,*

$$\Delta g = -\frac{\partial T}{\partial h} + \frac{\partial \gamma}{\partial h} N \, . \tag{B-8}$$

Confining attention to the point directly over the added mass (S = 0), equation B-8 gives

$$\frac{\Delta g}{g_o} = \frac{m}{M}\frac{R^2}{D^2} \quad . \tag{B-9}$$

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* loc cit

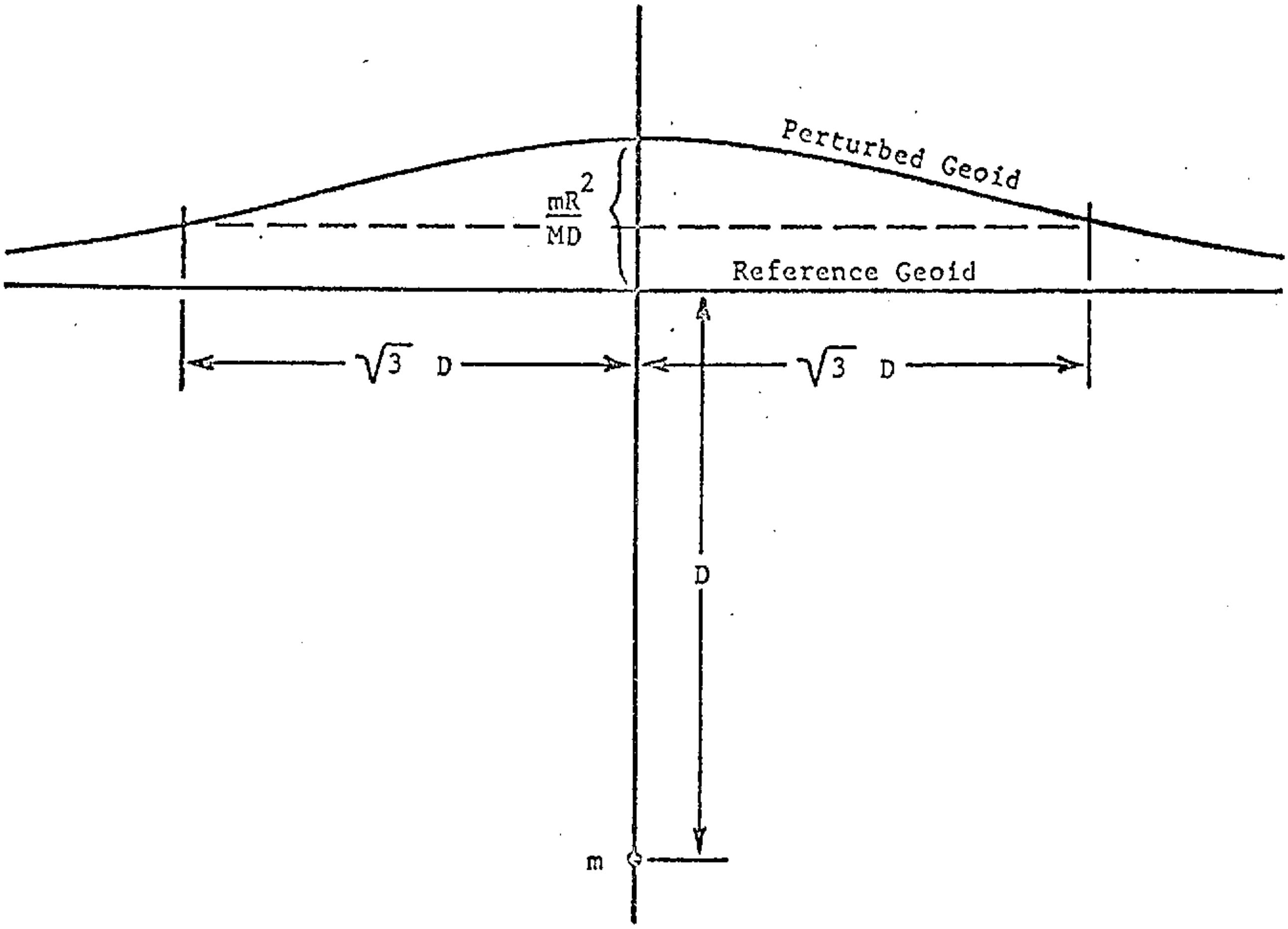

FIGURE B-3. PATTERN OF GEOID DISPLACEMENT CAUSED BY A POINT ANOMALY IN AN OTHERWISE UNIFORM EARTH

Example Application

In order to give more specific meaning to these results, an application to an assumed mineral deposit is considered. This deposit is assumed to consist of one cubic kilometer of iron ore, whose midpoint is one kilometer below the surface of the earth. Although, not exactly at point mass, it may be reasonably approximated as such for the required computations.

The average specific gravity of the material in the earth's crust is of the order of 2.5. Taking the density of the iron ore to be about twice this, then, the difference between the iron ore mass and the density of a like volume of average material would be about 2.5 gm/cm^3. A cubic kilometer of iron ore would then be represented by 2.5×10^{15} grams of meterial added to an otherwise homogeneous earth. Taking the mass of the earth to be about 5.4×10^{27} gm, and an earth radius of 6400 km, the value of N(0) computed from equation B-7 is

$$N(0) = \frac{mr^2}{MD} = 2\,\text{cm} \quad . \tag{B-10}$$

On the same basis, the gravitational anomaly from equation B-9 gives

$$\Delta g = g_o \frac{m}{M} \frac{R^2}{D^2} = 19 \text{ mgal} \tag{b-11}$$

where g_o is taken to be approximately 1,000 gals.

Conclusion

The substantial mass anomaly (19 mgal) considered here, produces a small effect on the location of the geoid (2 cm). It raises the geoidal surface which is about 2 cm at the center, and the geoid perturbation has a diameter or lateral extent of the order of 3.5 kilometers. If the ocean surface conforms exactly to this geoid, the effect will be extremely difficult to measure.

The gravitational anomaly, on the other hand is rather readily measurable, even at sea. Terrestrial measurements can detect anomalies perhaps an order of magnitude smaller than that in the example above. In the SEASAT application, however, the only means available is that of direct measurement of the geoid. As a practical matter, discrimination of the order of a centimeter or less, from a satellite 800 km away, when the wave heights are on the order of a meter or more, does not seem especially likely. In essence, the geoidal perturbation seems to be too small to permit location of mineral deposits by this technique.

Derivation of gravity anomalies from SEASAT altimeter data to the accuracy required for offshore mineral prospecting does not appear to be feasible - a finding suggested by the illustrative calculations above and in Appendix A. However, it should be noted, satellite determination of the geoid to a high degree of accuracy will likely contribute to improved marine mineral surveying in other ways. At present, both ocean bottom gravimeter and surface ship measurement suffer from relatively inaccurate ship position information. Information derived from SEASAT data can make a significant contribution in improving position and velocity determination, and, hence, make possibly higher quality surface ship gravity and seismic survey results.

APPENDIX C

ECONOMIC BENEFITS OF SEA ICE REMOTE SENSING SYSTEMS*

by

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ABSTRACT

Weather and sea conditions, particularly the formation and movement of sea ice, pose severe problems for Arctic exploration, transportation and resource development. Strategic and tactical information about sea ice can be used to improve the productive outputs of Arctic exploration and transportation industries. Similar information can improve transportation in the St. Lawrence Seaway and Gulf, and along the Labrador and Newfoundland coasts. The present information system is useful, but future required systems are complex and involve an infrastructure of advanced remote sensing, computing and communications technologies. This paper presents a preliminary analysis of the economic benefits and costs of such systems.

1. BACKGROUND

Remote sensing technology

Aircraft and satellites are used as platforms to carry sensors. Two types of sensors are commonly used: (1) those that act as passive monitors of natural and cultural emissions or reflections from the earth's surface and near-surface environment (e.g., cameras, radiometers, multi-spectral line scanners), and (2) those that actively "illuminate" targets and receive reflected radiation (e.g., radar, laser fluorosensors). See e.g., references (2, 10, 11, 12, 14).

Remote sensing applications

The effective use of remote sensing for resource management, environmental control, and other purposes, involves the following stages:

1. data acquisition (airborne and satellite)
2. data processing (production of images and data)
3. data interpretation (manual and machine)
4. application to management decisions
5. measurement of physical effects of decisions
6. evaluation of economic benefits and costs.

Public and private enterprises are involved at all stages.

Remote sensing may be used for mapping static phenomena (e.g., geomorphology) or for monitoring dynamic phenomena (e.g., crop growth). The applications are too numerous to list here, but descriptions may be found in various publications; see e.g., (6, 10).

Among the promising applications in Canada are the following:

- transportation routing (sea ice)
- hydropower forecasting (snowmelt)
- crop production (inventories, vigour, yield)
- forest insect control
- pollution control (e.g., oilspills)
- land use planning.

Many other Canadian applications are also under intensive investigation by scientists and resource managers.

Sea ice application

The history of exploration in the Canadian Arctic is long and full of drama and tragedy. It includes the voyages and treks of Frobisher (1577), Hudson (1610), Hearne (1769), Mackenzie (1789), Franklin (1844), Peary (1909), and Stefansson (1913-18). It also includes the less publicized but not less important modern explorations of the Geological Survey of Canada, and the continuing Arctic work of countless scientists, entrepreneurs and pioneers of the 1970's.

Basque whalers were working in Davis Strait as early as 1520, and there is evidence that Vikings had established permanent fishing settlements in the Ungava Bay area centuries earlier than that. From whaling in the eastern seas to gold mining in the Klondike, the history of economic enterprise in the Canadian Arctic has been one of sporadic bursts of activity and very slow growth. Today there is again a burst of activity, with oil and gas replacing gold as the lure, but this time it promises to lead to a sustained long-run trend of economic investment and production.

Remote sensing can be used in the Arctic to expedite exploration work, to expedite transportation logistics, to monitor pollution and to provide a data bank for a variety of scientific investigations (e.g., ecology, oceanography, geology). This paper deals with the particular application of remote sensing to the monitoring of sea ice for the purpose of improving navigation and exploration in ice infested waters, including the east coast and Gulf of St. Lawrence as well as the Arctic.

2. MISSIONS OF GOVERNMENT AGENCIES

Multiplicity of interests

The Canadian Departments of Communications, Defence, Energy, Mines and Resources (DEMR), Environment (DOE), Indian Affairs and Northern Development, Transport and others are involved in a multitude of studies, research and development missions and operational missions in the Arctic and continental shelf areas. Their concerns include geology, minerals, soil, water, ice, plant life, animal life, ecology, pollution, weather, telecommunications, commercial development, and not least humans and their physical and social environments.

Each of the departments has its own needs for Arctic remote sensing support services, and the orchestration of such services poses special organizational problems. Two agencies play particularly important though not exclusive roles in providing remote sensing support services: the Canada Centre for Remote Sensing and the Atmospheric Environment Service.

Canada Centre for Remote Sensing

The Canada Centre for Remote Sensing (CCRS), a branch of the Department of Energy, Mines and Resources (EMR), forms the hub of a National Program in Remote Sensing, involving federal and provincial agencies, universities, regional associations and private enterprises. The Program involves an extensive and complex infrastructure of physical systems and human organizations dispersed across the country. The CCRS provides services to other agencies, under the guidance of the Inter Agency Committee on Remote Sensing (IACRS). It receives scientific and technical advice through a grass roots committee of 200 scientists and engineers called the Canadian Advisory Committee on Remote Sensing (CACRS). See e.g., papers by Morley and Clough (8) and Clough (14), describing the National Program and the mission of the CCRS.

The three main activities of the CCRS are: (1) satellite remote sensing, (2) airborne remote sensing, and (3) applications development. The CCRS annual budget is over $6 million.

Under an agreement between Canada and the U.S., NASA's Earth Resources Technology Satellite (ERTS-1), transmits data directly to the CCRS satellite receiving station in Prince Albert, Saskatchewan. The data are stored on high density magnetic tapes and flown to Ottawa for precision computer processing into photographic imagery and computer compatible tape outputs. Imagery is processed, archived and distributed in various forms by the National Air Photo Library (NAPL). The data processing system has been described by M. Strome (17).

A "Quick Look" facility exists at the Prince Albert receiving station, so that uncorrected satellite imagery can be recorded immediately on photographic film. The "Quick Look" imagery is processed and distributed commercially by Donald Fisher and Associates

Limited, in a variety of forms including microfiche records mailed daily to users.

The CCRS airborne remote sensing facilities include four aircraft equipped with a variety of camera packs, sensors and airborne data acquisition systems. Computer interfaces are being developed so that multi-spectral data from airborne systems can be processed by the Ground Data Handling Centre in the same way that satellite data are presently processed.

The CCRS applications development program involves the development of automated methods of data interpretation and information systems to assist resource managers and other users. One of the main aims is to assist other agencies to plan their own remote sensing systems as component parts of a national system.

Atmospheric Environment Service (AES)

The AES, a branch of DOE, provides an ice advisory service from its Ice Forecasting Central facility in Ottawa, as well as general weather forecasting and other atmospheric environment services. As part of its operational mission, Ice Central operates two aircraft for ice reconnaissance in the St. Lawrence River and Gulf areas in winter and in the Arctic at other times.

The aircraft, which are operated under contract by commercial firms, carry special navigational and remote sensing equipment and trained observers. The sensor systems include cameras, a laser profilometer, a ground mapping radar and an imaging infrared line scanner. The aircraft are limited chiefly to daytime, fair-weather operations in areas within reach of available air bases (e.g., Inuvik, Frobisher, Thule). Possible future systems include side looking airborne radar (SLAR), and passive microwave imaging sensors, both of which can be used under cloud conditions, night and day.

Facsimile ice charts and other data are sent by telephone lines from remote air bases to Ice Central, where they are combined with other data from satellites and historical data banks and retransmitted to radio stations at Edmonton, Halifax, Frobisher and Resolute, from whence they are broadcast to ships at sea. Radio reception in the Arctic is subject to interference and occasional blackouts. The indirect relay from the original air bases to the ships takes about 24 hours under normal conditions, but much longer under worst conditions. In some cases, however, airborne observers can transmit hand-annotated facsimile ice charts by radio directly to ships within about 100 miles of the aircraft.

As a side payoff from AES weather satellite operations, Ice Central has obtained some useful low-resolution strategic sea ice information from the TIROS and ESSA satellites. NOAA 2 and 3, the most recent weather type satellites, have very high resolution radiometers (VHRR) systems, as well as conventional lower-resolution systems both producing images in visible and thermal infrared spectral bands. The VHRR system is particularly important for daily strategic sea-ice reconnaissance because it can produce IR images at night under cloudfree conditions (30%). However, at the time of this writing the AES does not have a receiving station to obtain the broadband VHRR transmissions. The images have to be obtained after delay by mail from the U.S.

Ice Central also obtains ERTS "quick-look" images by mail from the CCRS, which receives transmissions directly from the ERTS-1 satellite (see above). The ERTS pictures have very high resolution compared with the weather satellite pictures (300 feet versus ½ mile). They provide useful tactical and strategic ice forecasting data, under daytime cloud-free conditions in four spectral bands (two visible, two near-infrared). However, the coverage is limited to a maximum of 10 consecutive days in every 18-day cycle of polar orbits. The mail delay is about 2 days.

3. FUTURE OPERATIONAL SYSTEMS

The development of operational remote sensing information-communication systems has been evolutionary, depending on state-of-the-art technological changes. A substantial transition period is required to develop organizational modes as well as technology, and to progress from experimental systems to "quasi-operational" systems.

For example, the Canadian ERTS satellite program was originally funded by the government as a four-year, $25 million experimental program, following U.S. developments. However, the ERTS program has been gradually evolving from an experimental mode to a "quasi-operational" mode, providing useful information almost routinely, through a variety of organizational arrangements and communication channels, to private and public users alike. As planned, at some future time it will undoubtedly become part of a more comprehensive "fully-operational" management information system to serve resource managers and environmental control agencies on a routine basis.

The CCRS is presently engaged in studies of potential benefits and costs of postulated future "quasi-operational" and "fully-operational" systems, as a basis for program planning. The "scenarios" are based on limited data, preliminary engineering, and assumptions about budgetary feasibility; a great deal more analysis, experimentation, engineering and planning would be required before implementing the more elaborate future systems envisaged. The preliminary analysis of benefits and costs of Arctic ice remote sensing described herein is only part of a larger study of a variety of applications. For purposes of preliminary analysis, the following broad "scenarios" are put forward.

A. Near-term augmented AES/CCRS information systems

This scenario involves two main CCRS elements, as follows: (1) modification of the Prince Albert satellite receiving station to receive VHRR data from the NOAA weather satellites, as well as ERTS data, and (2) installation of a radio station and facsimile equipment at Prince Albert, to transmit "quick-look" NOAA and ERTS images directly to ships in the Arctic, and also to existing AES stations. It also involves two main AES elements: (1) installation of a receiving station to obtain NOAA and other proposed future satellite transmissions, and (2) integration of the new receiving station with IceCentral forecasting and broadcasting systems at Edmonton or Ottawa.

B. AES Side-Looking Airborne Radar (SLAR), added to A above

This scenario involves the addition of SLAR to AES operational aircraft, to provide all-weather (cloud penetration), day-night capability for radar mapping of ice fields along ship routes, as an additional element to the system described in A. The satellite images would provide broad strategic coverage, as a basis for more detailed tactical coverage by SLAR along strategic shipping routes, and close tactical support of convoys under icebreaker escort. The proposed systems could be implemented within a year.

C. Advanced information systems

This scenario would involve the same basic elements described in A and B above, with extended airborne and satellite remote sensing coverage. However, future radio relay would be via satellite. For example, facsimile images could be transmitted from Prince Albert and other centres to a communications satellite, and then retransmitted from the satellite to the ships. This would provide more reliable radio reception with much less image degradation. For some ships, such as survey ships, icebreakers and convoy leaders, image transmissions could be received directly from earth resources satellites and weather satellites. However, the shipboard antennas and image processing equipment would be relatively expensive. Further systems design studies and experiments are required to prove the economic feasibility of these advanced communications systems.

This scenario would also involve the interfacing of environmental reconnaissance and data bank systems (including sea ice data) with the logistical planning systems of the Coast Guard and commercial shipping firms. Fully integrated operational systems would involve organizational and technological elements of several federal government departments and agencies, various private enterprise groups and provincial agencies, and international connections with agencies of the U.S. and other nations.

Such systems could be implemented over the next 10 to 15 years, in phase with northern oil, gas and mineral transportation developments, with the AES playing a pivotal role as an extension of its ice advisory service, and with the CCRS playing a supporting service role.

4. THEORETICAL BASIS OF MEASURING BENEFITS

Common Property Resources and Second-Order Effects

Remote sensing information produced by the government is treated as a common property resource. It represents valuable information about the world which cannot be reduced to individual ownership. Consumption of the information by one person does not impair another person's ability to consume the same information. One of the roles of government is to regulate the use of common property resources such as air, water and certain kinds of information. As a common property resource,remote sensing information produced by the government does not enter into the normal market exchange process, and therefore cannot be valued directly in market price terms.

How, then, can remote sensing information produced by the government be valued in economic market-price terms? It can be valued indirectly in terms of a second-order effect, as follows: (1) as an input factor or production, it permits the choice of a more efficient production function from a catalogue of feasible production functions (see e.g., Morishima (9) and Burke and Clough (1)); (2) the more efficient production function will yield a different supply curve, with a shift to lower supply prices; (3) the shifted supply curve will yield a different supply-demand equilibrium point, and (4) the difference in equilibrium prices and quantities will yield a change of consumers' utilities (measured in money terms), which is used as a measure of gross benefits.

Postulates

As a basis for measuring economic benefits, we adopt the following postulates, which are consistent with the general framework of applied welfare economics:

(1) the competitive demand price for a given unit measures the value of that unit to the demander,

(2) the competitive supply price for a given unit measures the value of that unit to the supplier,

(3) both demanders and suppliers attempt to maximize their own utilities, which can be expressed in terms of supply and demand prices and quantities (i.e., they do behave according to the definition of economic man),

(4) the benefits (costs) of a policy or a project to an individual are measured in terms of a change in utility, which in turn is expressed in terms of changes of supply-demand equilibrium prices and quantities,

(5) the benefits (costs) accruing to each individual are added to obtain an aggregate measure of social benefits (costs).

Social Benefit Model

Suppose that final consumer demands are fixed and that a policy or project has the effect of shifting supply curves. Eminent economists have advocated that the benefits of the project should be measured in terms of changes in consumer surplus resulting from a shift of the supply-demand equilibrium point. See Harberger (5) for a presentation of common criticisms and rebuttals concerning the use of the consumer surplus measure.

Because of the ambiguities of the linguistic conventions used to describe the theory, a formal model is required. Following the paper of Harberger (5), let us consider an exhaustive set of goods (services) whose quantities are denoted by X_1, $X_2, \ldots, X_n$. Assume that an individual consumer's utilities can be expressed in terms of a cardinal utility function,

$$U = U(X_1, X_2, \ldots, X_n), \tag{1}$$

which is continuous and concave and has at least first and second partial derivatives.

Now consider equilibrium prices paid by the consumer, P_i^o, for $i = 1, 2, \ldots, n$. The consumer's expenditure equals his budget (disposable income), B, as follows:

$$B = \Sigma_{i=1}^{n} P_i^o X_i \quad . \tag{2}$$

Assuming that the consumer maximizes his utility, subject to his budget constraint, his optimal expenditures satisfy well-known conditions which are derived by the standard Lagrangian method:

$$(\partial U/\partial X_i)/P_i^o = \lambda^o, \text{ for } i = 1, 2, \ldots, N. \tag{3}$$

The solution of (2) and (3) yields the point of maximum utility, X_i^o, for $i = 1, 2, \ldots, n$, the marginal utility of money, λ^o, and the corresponding maximum value U^o.

Incremental changes in equilibrium prices, P_i^o, result in changes X_i^o and hence U^o in the neighbourhood of the point of maximum utility. Using standard methods of Taylor series expansions, chain rules of differentiation, and some algebraic manipulation, we obtain the second-order approximation:

$$\Delta U^o/(\lambda^o + \frac{1}{2}\Delta\lambda^o) \cong \Sigma P_i^o \Delta X_i^o + \frac{1}{2}\Sigma\Delta P_i^o \Delta X_i^o. \tag{4}$$

The left hand side represents an increment of utility in money terms, since its denominator is the mean value of the marginal utility of money before and after the change. The right hand side, which is empirically measurable, is equivalent to the left hand side. See Harberger (5).

The utilities of individual consumers, and changes in utilities, can be aggregated by simple addition, on the premise that additivity is democratic. Thus the terms on the right hand side can be summed over all individuals. In the following discussion, and references to the equations above, all values are <u>aggregate</u> values after summation.

Consider supply and demand curves for the various goods, with simultaneous equilibrium prices and quantities given by P_i^o, X_i^o, for i = 1, 2, ..., n. Suppose that a policy or projecy causes shifts of the supply curves, changing the equilibrium prices and quantities to $P_i^o + \Delta P_i^o$ and $X_i^o + \Delta X_i^o$ respectively. Then equation (4), applied in the aggregate, measures the corresponding benefits. Under undistorted equilibrium conditions, the first term on the right hand side represents a change in net national product at constant prices, and the second term represents a change in consumer surplus. To avoid semantic and interpretational problems, and the necessity of spelling out special conditions, let us simply call the sum of both terms the <u>social benefit</u>, measured in dollars.

Supply-Demand Model for Marine Surveys

The use of remote sensing information allows a ship's pilot to avoid delays caused by sea ice. The reduction of delays amounts to an increase in productive output, and a corresponding reduction of the average unit cost of output. Under normally assumed competitive conditions, the result would be a shift of the supply curve (lower supply price at any quantity).

On the supply side, let us first consider the fleet of Arctic marine survey ships. The production output of a ship can be described in terms of line-miles of survey work completed. Let us assume that this is a random variable X having expected value μ and standard deviation σ . Let us assume that the ship's operators calculate a supply price P as follows:

$$P = R/\mu = (1 + r)C/\mu \qquad (5)$$

where C is fixed total cost, r is profit margin (decimal fraction), and R is expected revenue. In fact, the total cost has both fixed and variable components, but the variable component is relatively small.

On the demand side, let us assume that the petroleum firms will demand any quantity of marine survey work up to the supply capacity of the ships, at the quoted supply price. Thus the expected supply-demand equilibrium point would be at quantity μ, price P^o, where P^o is given by (5).

Suppose that the use of remote sensing information reduces survey ship delays caused by sea ice, thus increasing production. The result is to increase the expected value μ to $(\mu + \Delta\mu)$, and to reduce the supply price from P^o to $(P^o + \Delta P^o)$, without changing C or R, such that

$$P^o + \Delta P^o = R/(\mu + \Delta\mu). \tag{6}$$

Equations (5) and (6) yield the result

$$\Delta P^o = -(P^o/\mu)\Delta\mu - (1/\mu)\, \Delta P^o\, \Delta\mu, \tag{7}$$

or the first-order approximation

$$\Delta P^o = -(P^o/\mu)\, \Delta\mu. \tag{8}$$

Assuming that supplies and demands of other goods remain unaffected by the change $\Delta\mu$, we can calculate the expected social benefits by substituting from (8) into (4), obtaining

$$P^o\, \Delta\mu + \frac{1}{2}\Delta P^o\, \Delta\mu = P^o\, \Delta\mu - \frac{1}{2}(P^o/\mu)\, (\Delta\mu)^2. \tag{9}$$

This procedure may be referred to as "partial equilibrium analysis".

Supply-Demand Model for Arctic Shipping in Summer

On the supply side, let us consider a ship that is specially designed (strengthened) for Arctic service, and that is contracted primarily to make one or two trips to the Arctic in the summer shipping season (about 6 weeks). The ship is also contracted for ordinary work in other seas in other seasons. The scheduled time for the ship is thus constrained to satisfy the equation

$$D_1 + D_2 = T, \tag{10}$$

where D_1 is the number of days in Arctic charter, D_2 is the number in ordinary charter, and T is the total number of working days in the year. Let us assume that D_1 and D_2 are correlated random variables with expected values μ_1 and μ_2 respectively, where

$$\mu_1 + \mu_2 = T. \tag{11}$$

A change $\Delta\mu_1$ implies a corresponding change

$$\Delta\mu_2 = - \Delta\mu_1. \tag{12}$$

Now let us define the quantities of outputs for the ship as follows:

$X_1 = 1$, a unit season-charter for Arctic work,

P_1 , the corresponding supply price,

$X_2 = D_2 = (T - D_1)$, ship-days in other charter,

P_2 , the corresponding supply price,

$E(X_2) = E(D_2) = \mu_2$, the expected value of X_2.

Let us assume that the ship's operator controls the supply price P_1 but must meet the world equilibrium price P_2^o, so that

$$P_2 = P_2^o. \tag{13}$$

Let us assume that the ship's operator calculates his supply price P_1 to make up the difference between his cost (including profit) and expected revenue from ordinary non-Arctic charter, as follows:

$$P_1 + P_2^o\mu_2 = (1 + r)C, \tag{14}$$

where C is the total annual cost of the ship and r is the profit margin. (In fact, the total cost has annual fixed and variable components, but the variable component is assumed to be relatively small, assuming that the ship is fully utilized all year.)

On the demand side, let us assume that the Arctic transport demand curve is perfectly inelastic within some feasible range of demand price. The transport users negotiate the Arctic charter at the offered supply price P_1, and it becomes the equilibrium price P_1^o, viz.,

$$P_1 = P_1^o. \tag{15}$$

Then, from (14),

$$P_1^o + P_2^o\mu_2 = (1 + r)C. \tag{16}$$

Now suppose that the use of remote sensing reduces delays caused by sea ice, thereby changing the expected value of μ_1 to $(\mu_1 + \Delta\mu_1)$, where $\Delta\mu_1$ is a negative quantity. Correspondingly, P_1^o changes to $(P_1^o + \Delta P_1^o)$. Then, from (16), we have

$$\Delta P_1^o = -P_2^o \Delta\mu_2 = P_2^o \Delta\mu_1, \tag{17}$$

since $P_2^o = 0$. (The world equilibrium price P_2^o remains unaffected by the change $\Delta\mu_1$.)

We can calculate the expected values of the partial social benefits related to shifts in supply, using (17) and (4). First, the benefit related to a shift of the supply curve for Arctic transportation is zero because $X_1^o = 0$ (demand is perfectly inelastic at P_1^o). Thus,

$$P_1^o X_1^o + \frac{1}{2} P_1^o X_1^o = 0. \tag{18}$$

However, the expected benefit related to a shift of the supply curve for <u>other</u> transportation is positive, as follows:

$$E(P_2^o\Delta X_2^o + \tfrac{1}{2}\Delta P_2^o X_2^o) = E(P_2^o\Delta X_2^o)$$

$$= P_2^o\Delta\mu_2 = -P_2^o \Delta\mu_1 = -\Delta P_1^o. \tag{19}$$

Thus the expected benefit is expressed in terms of the market value $P_2^o\Delta\mu_2$ of the Arctic ship-days released for alternative use in other seas.

5. GROSS ECONOMIC BENEFITS

The main items of gross benefits of sea ice monitoring are summarized under five main headings: (1) Arctic seismic surveys, (2) Arctic shipping, (3) Arctic pipelines, (4) Arctic and east-coast offshore drilling, and (5) St. Lawrence Shipping. See McQuillan and Clough (7).

Arctic seismic surveys

Seismic survey vessels tend to operate more independently than most ships in the Arctic, particularly in the high Arctic. They go without adequate support from Canadian icebreakers and without adequate aircraft ice reconnaissance. In such circumstances, satellite remote sensing coverage is very helpful.

A commercial seismic survey company, for example, was using ERTS images in the summer of 1973 as an aid in the tactical navigation of a ship they were operating in the high Arctic. (See Oilweek (13).) They broadcast ERTS information verbally from Edmonton, after a two-day delay in receiving the "Quick Look" images from Prince Albert. Such information from a single ERTS image made it possible for the ship operating in Norweigian Bay to survey an area that it would otherwise have missed. The image showed the presence of open water beyond a large ice floe, and a path to the open water. In this case an additional one-day survey output of 75 line-miles, that would otherwise have been lost, represented over $100,000 in revenue to the company. A retrospective examination indicated that ERTS data could have saved the ship 2 or 3 more days of productive time.

Based on expert opinions of commercial operators, Arctic navigators and remote sensing specialists, it has been estimated (7) that marine survey ships could save an average of about four days per ship-season of lost time if they could receive faster transmissions of ERTS and NOAA data from Prince Albert, as outlined earlier in the scenario for the near-term augmented information system.

If all the present exploration permits are carried through, it has been estimated (13) that 180,000 kilométers of marine seismic data, representing about 36 ship-seasons, will be required to explore the areas accessible to ice-strengthened vessels. By the end of 1973 about fifteen ship-seasons had been completed, leaving about 21 ship-seasons to be completed in the next seven years. The estimated average increase of survey output, related to the proposed near-term augmented information system (Scenario A), would be about 12 ship-days per year for seven years. It is convenient to use ship-days rather than line-miles as the unit of measurement in equation (9). Estimating μ = 120 ship-days per year, $\Delta\mu$ = 12, and P^o = 100,000 dollars per ship-day, from (9) we obtain the following estimated gross benefits:

$$P^o\ \Delta\mu - \frac{1}{2}(P^o/\mu)\ (\Delta\mu)^2 = 1{,}200{,}000 - 120{,}000$$

or approximately $1 million per year for the next seven years. If implementation of the system were delayed until 1975, the stream of gross benefits would start later and carry on for only six years. These figures are conservative, since a major discovery could lead to an expanded program of seismic surveys.

As exploration activity increases in the Arctic, the amount of on-ice winter seismic survey work is increasing, to cover areas not accessible to the more economical marine surveys. Surveying output can vary from 150 to 300 line-miles per crew-month. In the winter of 1973-74, four crews are going out on the ice in Sverdrup Basin for a three-month period.

If the on-ice survey areas could be flown by SLAR-equipped aircraft based on ERTS and NOAA prior satellite information, it has been estimated (7) that on-ice survey production could be increased by an average of 60 line-miles per crew-month, or about 720 line-miles for the year. The estimated price is about $4,000 per line-mile. Using the same model as for marine survey work, the same equation (9), and estimated values μ= 2,700 line-miles per year, $\Delta\mu$ = 720, P^o = 4,000 dollars per line mile, we obtain the following estimated gross benefits:

$$P^o\Delta\mu - \frac{1}{2}(P^o/\mu)\ (\Delta\mu)^2 = 2{,}880{,}000 - 384{,}000$$

or approximately \$2.5 million per year. It is expected that such activity will continue for at least 7 years.

Recapitulating, the estimated average annual gross benefits of improving marine and on-ice survey production would be as follows, in \$ millions:

	Marine	On-Ice	Total
1. Near-term augmented info system	1.0	-	1.0
2. All-weather surveillance capability added to 1	-	2.5	2.5
TOTAL	1.0	2.5	3.5

Such annual benefits would begin at the time the proposed systems are implemented and it is expected they would continue at least until 1980.

Arctic shipping, summer season

Over 150 ships operated in the Arctic during the 1973 season. Fourteen of these were Canadian Coast Guard ships. Many of the commercial ships were involved in Arctic re-supply. In the Western Arctic, one company had 28 ships and 167 barges and another had 10 ships and 26 barges. The precise total number of ships which operated in the Arctic in 1973 does not appear to be readily available but a conservative estimate would be over 100 ships in the Eastern Arctic and over 50 in the Western Arctic.

There are many examples of ships being delayed for extensive periods of time due to lack of knowledge of ice conditions. For example, in 1972 a survey ship of one exploration company spent 6 weeks in difficulty in ice congested waters. It has been estimated (7) that the probability was about 0.3 that the delay could have been avoided if ERTS-1 and NOAA satellite data could have been relayed to the ship within a day, saving the ship's operators about \$1.5 million in lost revenues.

As another example, in the summer of 1972 a convoy of Canadian, Danish and Finnish ships, accompanied by Canadian Coast Guard icebreaker escort, was held up more than a week by ice. Some ships were unable to reach their proposed destination and the cargo had to be airlifted at considerable expense. Satellite data on sea ice would have been useful in this case to find a way to avoid the delay.

The Canadian Coast Guard operates 5 yeavy and 6 medium icebreakers in the Arctic for 3 or 4 months each year, the most modern heavy one being the 27,000 hp "Louis St. Laurent". The expert opinions of the longer-term experienced people who have captained ships in the Arctic is that an increase of at least 25% in efficiency in the productive assignment of these icebreakers could result from improve information on ice conditions (7). Efficiency increase would come from better tactical, strategic, and planning information. Tactical information applies to ice conditions within a short distance of perhaps 100 miles of the ship and permits choice of the easiest route. Strategic information applies to a wider area and forecasts trends over a period of a week or more. Planning information results from a buildup of the present body of basic information on ice conditions, properties and movement. Better planning and strategic information would, for example, permit an icebreaker captain to decide that he shouldn't sail into an area before a certain day. The icebreaker could meantime be employed elsewhere, helping to satisfy the exceedingly heavy demands on its services.

The 25% increase in efficiency would apply to all ships operating in the Arctic. Ships, whether escorted by icebreakers or operating independently, would operate more efficiency. Icebreakers could escort their convoys to their locations faster and be available to assist other shipping. One way of expressing this increase in operating efficiency is in terms of reduced delay times and hence increased productive output. The reduction of delays would result from real time acquisition of current satellite imagery, all weather reconnaissance such as provided by a satellite or aircraft equipped with a microwave imaging device, ice thickness measurements in the vicinity of the ship, and better forecasting of ice conditions as obtained by a better historical knowledge of ice conditions in an area.

The following table shows estimated average increases in productive times of a ship under Arctic charter, as a result of the use of alternative remote sensing systems:

	Productive increase ship-days per ship-season
1. Near-term augmented info system	3-4
2. All-weather reconnaissance capability added to 1	7-8
3. Integrated measurement and planning added to 1, 2.	3
TOTAL.................................	13-15

The ships used for Arctic transportation in the summer are mostly in the 2,000 to 10,000 ton range and are used largely for re-supply of Arctic settlements and bases. It is estimated that the average charter value of all the ships in this class is about $5,000 per ship-day in the Arctic, and about $4,000 per ship-day in other seas.

The movement of supplies into the Arctic Islands is expected to increase rapidly in the next few years as exploration increases. Current exploration and other economic activity is approaching a value of one hundred and fifty million dollars per year and is expected to rise to 500 million dollars per year by 1981. This will result in a rapid increase in the numbers of ships and in the quality of ships used. At present 200,000 tons per year are required in the Eastern Arctic. By 1980 at least 700,000 tons per year in-bound will be required.

Although super vessels may be constructed for removal of minerals or petroleum out of the Arctic (see following section), small vessels will continue to be used for re-supply operations because of small consignments for many sites and the problems of inshore water depths. The increase in in-bound materials will probably increase the number of ships in the Arctic from 150 in 1973 to about 400 in the summer season of 1980. Using equation (19), the value P_2^o = 4,000 dollars per ship-day released to work in other seas, and the above traffic levels, we obtain the following table. The figures are in $ million per year.

	Added Average annual gross benefit per ship	Added Gross benefit 1974 level (150 ships)	Added Gross benefit 1980 level (400 ships)
1. Near-term augmented info system	.012	1.8-2.4	4.8-6.4
2. All-weather reconnaissance capability added to 1.	.032	4.2-4.8	11.2-12.8
3. Integrated measurement and planning added to 1,2.	.012	1.8	4.8
TOTAL (rounded)..........	. 06	8-9	21-24

It is essential that about 30% of the gross benefits of item 2 above would be achieved with the airborne SLAR system of Scenario B. The remaining 70% would be obtained with the advanced systems of Scenario C, including satellite and airborne all-weather microwave sensors.

The above estimates seem conservative and would have to be increased if decisions are made to take oil, gas and other minerals out of the Arctic. For example, in-bound shipments of machinery, pipe and other materials would be required to develop the oil and gas collection systems. The tonnages would be very large but they are difficult to estimate on the basis of present knowledge. The locations of oil pools, inter-island and overland collection pipelines, and trans-shipment ports are not yet known.

Better strategic and planning information could also result in both a longer shipping season in the Arctic and extended operations over a wider area. However, extension of the season would require changes of the Canadian Arctic Waters Pollution Prevention Regulations, which restrict the dates of movement. Extension of the season and better ice surveillance would probably lead to substantial reductions of insurance rates. These ramifications have not been accounted for above. Operational experience would be required before such effects could be estimated accurately.

Arctic shipping - year round outbound

Figure 1 is a summary of estimates of oil and gas and mineral reserves believed to exist in the Arctic.

In addition to the increased in-bound flow of supplies in summer, the outflow of materials from the north, which has already begun, is expected to increase dramatically. In 1973 Cominco commissioned the first ship load of 3,600 tons of lead-zinc out of Little Cornwallis Island and Strathcona Sound is expected to reach about 450,000 tons concentrate. Asbestos is also being shipped out of Ungava.

Studies have been made of the feasibility of shipping lead-zinc concentrates from Little Cornwallis Island to Europe during the summer open period allowed by the Pollution Prevention Regulations (August 25 to October 31 for Class 1A vessels in zone B), and also on a 6-month and 12-month basis. Ships with a carrying capacity in the 20,000 to 30,000 ton range have been considered, with special ice strengthening for winter use (7).

Each summer, a round trip between Cornwallis Island and Europe would take about 28 days. An ice-strengthened ship (class 1A) could take out three shiploads in a good season and two in a bad season. A total of 15 shiploads of 30,000 tons would be required to move the estimated production of 450,000 tons annually from the two mines at Little Cornwallis and Strathcona by 1977. Because the open season is so short, the first entry times and final exit times at the

TABLE 1

SUMMARY OF KNOWN MINERAL AND OIL AND GAS LOCATIONS IN THE EASTERN ARCTIC

Commodity	Area	Estimated Reserves	Estimated Annual Production	Life of Reserve	Probable Best Transportation Mode
		(Short Tons)	(Short Tons)		
Iron Ore	Mary River	130,000,000 Tons	4,000,000 Tons	30 Yrs. Plus	Surface Ship
Copper	Coppermine	4,000,000	20,000 Tons Concentrate	10 Yrs.	Surface Ship or Barge
Lead/Zinc	(Little (Cornwallis (Island	40,000,000	300,000 Tons Concentrate	14 Yrs.	Surface Ship
	(Strathcona (Sound	12,000,000	150,000 Tons Concentrate	14 Yrs.	Surface Ship
Sulphur	Axel Heiberg Island	10,000,000	500,000 Tons	20 Yrs.	Surface Ship
Copper/Nickel	Tehek Lake	25,000,000	500,000 Tons Concentrate	13 Yrs.	Ground Conveyor and Surface Ship
Oil/Gas	Arctic Islands and Coastal Plain	20.3 billion bbls. oil	50 million tons		Pipeline and Surface Ship
		242 trillion cu.ft. gas	6 million tons liquefied gas		
Oil/Gas	Offshore East Coast	47.5 billion bbls 307 trillion cu.ft.	50 million tons 6 million tons		Pipeline and Surface Ship

critical zone are crucial. It is estimated (7) that the availability of better sea-ice information from the proposed system of Scenario B would permit a reduction of the fleet of ships required from 8 to 7. The gross economic benefit would be the saving in capital cost between one class 1A ice-strengthened 30,000 DWT capacity ship for Arctic charter and one ordinary ship for charter in other seas, about $3 million or 500,000 annually over a 12-year period. (It is assumed that the shipping company will have opportunities to use any slack capacity for charter in non-Arctic seas. It is also assumed that it is optimal to minimize shipping costs and to have no stockpiling from season to season.)

In addition, it is estimated that the system of Scenario B would provide sufficient information to permit an average saving of about one day for each shipload, reducing the time spent in ice-infested waters from 10 to 9 days and the round trip from 28 to 27 days. Estimating $\Delta\mu = -15$ ship-days in 1977 and $P_2^o = 12{,}000$ dollars per ship-day under charter in other seas, equation (19) yields an average annual gross benefit of about $180,000.

It is further estimated that there would be a reduction of insurance rates because of the better navigation related to better ice surveillance. Assuming insurance premium rates of $3 per ton for 450,000 tons, a ten percent reduction of rates would yield a gross annual benefit of about $130,000.

After experience is gained in the operations of ships under better ice surveillance conditions, it is possible that further savings would be possible by changes in the Pollution Prevention Regulations to permit less costly classes of ships to operate in the same zones. However, such changes cannot be estimated at the present time and are not included here. If the 6-month or 12-month mode of operation were chosen, larger ships would be required. Daily microwave imagery would be required to give all-weather day-night coverage. These modes do not seem probably at the present time.

Because of the larger quantities involved, year round shipping would be necessary to transport oil, gas or Mary River iron ore out of the Arctic. In this case, very large icebreaking ships would be required to make headway in the ice and also because they are more economical per ton. Advanced remote remote sensing information systems would be required, as described in Scenario C.

Ice-breaking super vessels of 150,000 to 250,000 tons capacity (DWT) would be required for year-round oil shipping, priced at an estimated $50,000 to $75,000 per ship-day. Liquified Natural Gas (LNG) vessels would be priced at about $75,000 per day for 50,000 DWT capacity. Production forecasts are estimated as follows, beginning between 1980 and 1990 (7).

	Annual Production	Ship Capacity	Annual Shiploads	Number of Ships
Mary River iron ore	5 million tons/year	150,000 DWT	33	3-4
Ellesmere Island oil	1 million bbls/day	150,000 DWT	355	19-20
Liquified gas	6 million tons/year	50,000 DWT	120	7-8

These figures are, of course, subject to uncertainties that cannot be estimated except in terms of subjective probabilities of exports.

It is estimated that advanced information systems would be needed to provide timely sea-ice and weather information, as well as information about waiting-lines, loading-unloading bottlenecks, etc. It is estimated that the sea-ice information from remote sensing would provide the following savings of time and average annual gross benefits about 1990, based on savings of 2 days per ship-trip from Mackinson Inlet on Ellesmere Island or 4 days from Eureka.

	Days saved per shipload	Ship-days saved per year	Gross annual benefits $ million
Mary River iron ore	1	33	1.7
Ellesmere Island oil	2-4	710-1420	36-71
Liquified gas	3	240	18

Additional gross benefits could probably be realized through the reduction of ice damages to the ships, and insurance premiums (7). It is estimated that a 10 percent reduction of insurance premiums could be realized if advanced ice surveillance systems are employed, resulting in the following cost savings.

	Dollars per ton saving	$ million per year saving
Mary River iron ore	0.10	0.5
Ellesmere Island oil	0.10	5
Liquified natural gas	0.50	3

Arctic pipelines

The Geological Survey of Canada (GSC) in 1973 estimated the recoverable reserves in the Arctic Islands, Coastal Plain and Foxe Basin to be 20.3 billion barrels of crude oil and 242.0 trillion cubic feet of gas. On the Eastern Canada offshore they estimated 47.5 billion barrels of oil and 307.1 trillion cubic feet of gas. The Arctic Island reserves are more that the developed reserves in Canada. The discovery of major quantities of gas in the Sverdrup Islands in 1969 and succeeding years by Panarctic led to the formation in February of 1973 of a group called the Polar Gas Project to study the possibility of building a national gas pipeline from the Arctic Islands of Melville, King Christian, and Ellef Ringnes to southern markets. The members are Tenneco, Panarctic, Canadian Pacific Investments Limited, and Trans Canada Pipelines Limited. To support the economic feasibility of a gas pipeline out of the high Arctic, threshold reserves in the order of

25 to 30 trillion cubic feet must be assembled. The pipeline to deliver 3 ½ billion cubic feet per day, would involve some 2800 miles of about 48 inch diameter pipe and costs in the order of six to eight billion dollars (7).

The greatest difficulty in laying such a pipeline or other prospective pipelines in the north is the inter-island crossings which are more than five times more costly than land routing. The problem is the ice and the difficulty in devising a technique to lay pipe contoured to the ocean bottom (which may be 1800 feet) through ice perhaps nine feet deep in winter. Both the laying of the pipe and the logistics problems are severe, since pipe, supplies, machinery, and equipment must be taken in to the area, and the ships can only take them in during a short period in the summer.

The need for better knowledge of ice conditions is critical. Remote sensing techniques would help, particularly in the choice of inter-island crossings. For example, satellite imagery acquired over a period of years would show both the long term and seasonal pattern of ice movement, breakup and freezeup, the ice type and the extent of both land fast ice and pack ice. Airborne SLAR would show areas where pressure ridges form every year (sometimes 30 feet above and 150 feet below water). There would be many uses of specialized sensors for special purposes related to pipeline construction and maintenance, monitoring of leaks and environmental pollution, and supplying settlements.

No remote sensing information systems benefits have been estimated in relation to pipelines, because a pipeline would be an alternative to the ship transportation mode for which gross benefits have already been estimated above. The pipeline uncertainties seem to be greater than the shipping uncertainties.

Arctic and east coast offshore drilling and production

Specially designed equipment will have to be used for drilling in areas with more severe environmental conditions such as Baffin Bay, Beaufort Sea, or Jones Sound. In both the exploratory and development drilling phase, it will be necessary to protect sea-bottom wellheads from damage by scouring from pressure-ridge keels, ice island fragments and icebergs. Icebergs may scar from depths of 330 feet in southern Eureka Sound to 1,800 to 2,000 feet in the Baffin Bay-Labrador Sea area. It is clear that both for designing and operating facilities in the Arctic increased knowledge of ice properties and conditions is necessary.

Satellite and aircraft remotely sensed data will help in establishing design criteria for equipment to be used in different parts of the Arctic. Data collected over a period of time will help indicate whether drilling is feasible in certain areas and whether it can be carried out economically and without great environmental risks. In the inter-island areas satellite imagery is particularly useful in delineating land-fast ice.

Drilling operations require a constant surveillance of ice conditions in the area. For example, in the Beaufort Sea, ice free conditions are present only from about July 15 to Sept. 30. When open water drilling commences there (probably in 1977), it will be necessary to have a knowledge of when drilling can begin, and ice conditions during the drilling period. Once drilling commences every day lost could cost as much as $90,000. If an ice pack encroached on the drilling site, the drilling operation might be shut down. Alternatively they might move completely off the site in which case a week or more could be lost. The decision to quit drilling or move would depend on knowledge of the encroaching ice floe. If a large floe of multi-year ice was moving in on the site, the anchoring system could not hold and moving would be necessary. However, if aerial or satellite reconnaissance showed that the ice pack was scattered and not a hazard to operations, shut-down would not be necessary.

Exploratory drilling has already commenced in the east coast offshore area and losses have been incurred due to lack of adequate aerial reconnaissance. In January 1973 a well was spudded 215 miles east of Avalon Peninsula off Newfoundland. Ice moved in just after the well was spudded and drilling equipment had to be move. The work had to be redone later and $200,000 was lost. Operations would not have been started had it been known where there was an ice threat in the area. Drilling rigs used there are not covered by insurance if ice is allowed to encroach on them. These rigs are unreinforced and could be badly damaged. Their value is in the 20 to 25 million dollar range. A day of lost operation on the East Coast costs $50,000. Five each coast offshore drilling rigs have been in operation in 1973.

In the Arctic Islands offshore region it is expected that one well will be drilled in 1977 and possible three by 1980. In the Baffin Bay, Davis Strait area, probably two wells will be drilled in 1977 and 8 wells by 1980. A total of five wells by 1977 and nineteen by 1980 are therefore possible in these areas. Assuming only two days drilling could be saved for each of these wells by remote sensing, at $90,000 per day, savings of 900,000 dollars in 1977 and 3.4 million dollars in 1980 could be realized (Scenario B). It is also expected that two new wells will be drilled in the Beaufort Sea in 1977 and, if oil is found, possibly 8 by 1980.

St. Lawrence shipping

AES aircraft reconnaissance of ice conditions in the Gulf of St. Lawrence is currently quite good. Aircraft patrol the Gulf three times weekly monitoring the ice conditions, both visually and by remote sensing. Microwave ground mapping radar systems on board the aircraft give some all weather reconnaissance capability of ice conditions in the Gulf. Throughout the winter, ice advisories, forecasts and ice charts issued by Ice Central in Ottawa are broadcast daily by radio and radio facsimile. Radioed facsimiles are received by the ship usually about 14 hours after the aircraft flight. However, a facsimile of the observers' chart can be passed directly from the aircraft to the ship if it is within a range of 75 to 100 miles and has facsimile equipment onboard. Ice conditions can change very rapidly in the Gulf so rapid communications to the ship are desirable.

Ice conditions in the Gulf are sometimes quite bad, and delays even with current aircraft reconnaissance and icebreaker assistance are common. The Canadian Coast Guard Winter Operations Report 1971-2 states, "At times conditions were so severe that medium and light icebreakers were barely effective. The heavy units were forced to escort convoys of up to 7 ships in size; the optimal convoy size for heavy ice conditions is only 3 ships..."

A knowledge of ice thickness would help immensely in the Gulf in the routing of ships and deployment of icebreakers. About 50% of the ships using the Gulf are ice-strengthened and could proceed on their own about 85% of the time if they knew the ice thickness and the optimum route to take through the ice. It appears that the most effective addition to present technology would be the development of a remote sensor for measuring ice thickness accurately from AES aircraft. Better positional accuracy would also be required.

The use of an airborne microwave imaging sensor (e.g. SLAR) would yield an estimated average saving of about 6 hours for each ship moving through the Gulf of St. Lawrence in winter. If ice thickness could be sensed remotely and accurately, it is estimated that an average ship could save an additional 6 hours of delay time in 4 days required to steam from Cabot Strait to Quebec City. It is estimated that there will be 3,000 ship movements recorded in the Gulf of St. Lawrence in the 1973-74 winter season. At an average ship charter rate of $8,000 per ship-day, a 6-hour average saving of time per movement attributed to SLAR would have an average annual gross benefit of $6 million and a 6-hour saving attributed to ice thickness sensors would have an average annual gross benefit of $6 million. However, the latter begins only if and when an effective ice-thickness sensor is developed.

6. COSTS

The CCRS and the AES are set up to provide a spectrum of services for a multitude of purposes. Most of the information they generate is a common property resource, as described in

Section 4, and there is no proper basis for assignment of costs to specific end uses. (There are some exceptions, e.g. some airborne remote sensing services, where costs are assigned and charges levied.)

However, if the CCRS and AES systems are augmented to provide incremental benefits exclusively for a specific end use, such as navigation in ice infested waters, the incremental costs can be related to the incremental benefits for that particular end use. Preliminary estimates of these incremental costs are outlined below for the three scenarios described in Section 3 above.

In Scenario A, near-term augmented systems, the following incremental costs would be incurred:

1. Modification of Prince Albert Satellite Station (PASS) to receive NOAA (VHRR) as well as ERTS data. Capital cost to CCRS about $35,000.
2. Installation of a new 5 kw radio station operating on 5 frequencies at PASS, to send NOAA and ERTS "quick-look" images directly to ships. Capital cost to CCRS about $90,000 (including facsimile equipment. Additional operating cost to CCRS about $10,000 per annum.
3. Installation of a new NOAA (VHRR) receiving station at Edmonton or Ottawa and integration with existing AES operations. Capital costs about $200,000 to AES. Additional operating cost about $75,000 per annum.
4. Installation of high quality facsimile receiving equipment on about half of the 150 ships presently operating in the Arctic. Capital cost to the shippers would be about $12,000 per ship, or a total of $900,000. (Some ships are presently equipped for general-purpose facsimile reception.)

In Scenario B, it is estimated that SLAR systems would have a capital cost of about $2 million on two aircraft, and the additional operating costs would be about $100,000 per annum.

Scenario C may or may not include a new Canadian resource satellite with specially designed sensors and orbital characteristics to optimize all-weather, day-night coverage of the Arctic. Without the new satellite, the average annual costs would be about $8 to $10 million per year; this would include two additional aircraft equipped with SLAR, ice thickness sensors, airborne data handling equipment, satellite VHF or UHF communication systems, an additional receiving station to receive NOAA and ERTS type transmissions on the eastern seaboard, and possibly special receivers for NOAA and ERTS signals on board some icebreakers. It is estimated that this system could achieve about half of the gross benefits related to heavy all-year Arctic traffic circa 1990. The addition of a Canadian resource satellite could cost about $20 million per year and would acheive all of the estimated gross benefits cited above.

7. SUMMARY

Assuming that the near-term augmented systems of Scenario A become available in 1975, the systems of Scenario B become available in 1976, and the systems of Scenario C become available in 1980-1990, the gross average annual benefits are estimated below. The incremental benefits of B are added to A and those of C to A and B. All figures are in millions of dollars.

SOURCE OF BENEFITS	SCENARIO	1975	1977	1980	1990
Arctic Seismic Surveys	A	1.0	1.0	1.0	1.0
	B		2.5	2.5	2.5
	C	-	-	-	-
Arctic Shipping Inbound a,b,c	A	2.4-3.0	4.4-5.5	6.4-8.0	6.4-8.0
	B		3.7-4.0	5.3-5.9	5.3-5.9
	C			9.0-10.2	9.0-10.2
Arctic Shipping Outbound d	A	-	-	-	-
	B	-	-	-	-
	C	-	-	-	64-100
Offshore Drilling and Production c	A	-	0.5	1.8	3.6
	B	-	-	-	-
	C	-	-	1.8	3.6
St. Lawrence Shipping c,e	A	-	-	-	-
	B	-	4.0	4.0	4.0
	C	-	-	8.0	8.0

(a) It is conservatively assumed that the inbound Arctic shipping remains constant from 1980-1990.

(b) One third of the benefits of integrated measurement and planning are attributed to each of A, B, and C.

One third of the benefits of all-weather surveillance are attributed to B and the additional two thirds to C.

(c) The benefits for 1980 attributed to Scenario C would occur only if these systems were developed, by that time.

(d) Although all of the benefits for outbound shipping in 1990 have been attributed to Scenario C as it is expected that complex surveillance systems will exist at that time, some of these benefits could be obtained from Scenarios A and B.

(e) It is conservatively assumed that the number of ship movements in the Gulf remains constant through 1990. Two thirds of the benefits of all-weather reconnaissance are attributed to B and the remainder plus ice thickness measurements to Scenario C.

AGGREGATE BENEFITS	SCENARIO	1975	1977	1980	1990
	A	3.4-4.0	5.9-7.0	9.2-10.8	11.0-12.6
	B		10.2 -10.5	11.8-12.4	11.8-12.4
	C			18.8-20.0	84.6-121.8
TOTAL		8-9	16-18	40-43	107-147

It is estimated that all of the benefits of the systems of scenario C can be achieved if the system includes a Canadian resource satellite that is optimized for Arctic and ocean surveillance while half of the benefits could be achieved if the system does not include such a satellite

The incremental value of average annual cost of the proposed systems would be as follows:

SCENARIO	1975	1977	1980	1990
A	.2-.3	.2-.3	.3-.4	.4-.5
B	-	.3-.4	.4-.5	.5-.7
C without Canadian Satellite	-	-	-	7- 9
C with Canadian Satellite	-	-	-	20-30

All of the above estimates are based on experts' opinions and the authors estimate the range of accuracy may be $\pm 50\%$.

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